PB84-183516

Study of Carbon Monoxide Exposure of Residents of Washington, DC. and Denver, Colorado

Research Triangle Inst.
Research Triangle Park, NC

Prepared for

Environmental Monitoring Systems Lab.
Research Triangle Park, NC

Apr 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-183516

EPA-600/4-84-031
April 1984

STUDY OF CARBON MONOXIDE EXPOSURE OF RESIDENTS OF WASHINGTON, DC AND DENVER, COLORADO

By

T.D. Hartwell, C.A. Clayton, R.M. Ritchie, R.W. Whitmore,
H.S. Zelon, S.M. Jones, and D.A. Whitehurst

Contract No. 68-02-3679

Project Officer:
Gerald G. Akland
Environmental Monitoring System Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
Research Triangle Park, NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

228

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-84-031

2.

3. RECIPIENT'S ACCESSION NO. PB84-183516

4. TITLE AND SUBTITLE
Study of Carbon Monoxide Exposure of Residents of
Washington, D.C. and Denver, Colorado

5. REPORT DATE April 1984

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
T.D. Hartwell, C.A. Clayton, R.M. Michie, R.W. Whitmore,
H.S. Zelon, S.M. Jones, and D.A. Whitehurst

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Research Triangle Institute
Research Triangle Park, North Carolina 27709

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO. 68-02-3679

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Monitoring Systems Laboratory
U.S Environmental Proection Agency (MD-56)
Research Triangle Park, North Carolina 27711

13. TYPE OF REPORT AND PERIOD COVERED FINAL

14. SPONSORING AGENCY CODE EPA/600/08

15. SUPPLEMENTARY NOTES

Appendices in separate volume.

16. ABSTRACT

This report describes a study funded by the EPA and conducted by the Research Triangle Institute in 1982 and 1983 to evaluate methodology for collecting representative personal exposure monitoring (PEM) CO and corresponding activity data in an urbanized area. This involved telephone screening of households and sample selection of respondents in the metropolitan areas in and around Denver, Colorado and Washington, D.C. Data on CO breath levels were also collected in Washington, D.C. (PEDCo Environmental conducted the field work in Denver). The target population in both cities consisted of the non-institutionalized, non-smoking adults (ages 18-70) of these metropolitan areas. The data collected in the field were edited and appropriately weighted to produce CO exposure estimates for the target population.

Estimates of CO exposure for the winter of 1982-83 in Washington, D.C. were obtained using the data base constructed from the raw CO levels by activity data which consisted of hourly CO values on 712 respondents, activity patterns and corresponding CO levels on 705 respondents, and CO breath measurements corresponding to the PEM CO data on 659 respondents. The size of the target population was estimated to be 1.22 million individuals.

The weighted average maximum hourly PEM CO level in Washington, D.C. was 6.74 ppm. The average maximum 8-hour CO level was 2.79 ppm. The percentage of the population with maximum hourly CO values over the 35 ppm CO standard was estimated to be 1.28% while the percentage with an 8-hour maximum over the 9 ppm standard was 3.9%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Personal Exposure Monitoring Carbon Monoxide Exposure Activity Patterns Breath Measurements Washington, D.C. Probability Sampling Population Estimates		

18. DISTRIBUTION STATEMENT OPEN

19. SECURITY CLASS *(This Report)*

20. SECURITY CLASS *(This page)*

21. NO. OF PAGES 229

22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWARD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has the responsibility for: assessment of environmental monitoring technology and systems; implementation of agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency including the Office of Air, Noise and Radiation, the Office of Toxic Substances and the Office of Enforcement.

This document is a report of the development and application of personal exposure methodology for carbon monoxide to the residents of Washington, D.C., during the winter of 1982-83. This report discusses the methodology used in the study and the results of applying this methodology.

Thomas R. Hauser
Director
Environmental Monitoring
Systems Laboratory

TABLE OF CONTENTS

Page

Disclaimer ii

Forward iii

List of Tables viii

List of Figures xii

List of Exhibits xiv

Acknowledgements xv

Abstract xvi

1. INTRODUCTION 1

2. SUMMARY OF STUDY DESIGN AND PROCEDURES 4

3. SUMMARY OF STUDY RESULTS AND CONCLUSIONS 10

4. RECOMMENDATIONS 16

  4.1 Design Recommendations 16

  4.2 Recommendations Concerning Field Operations and Data Collection 17

  4.3 Recommendations for Further Statistical Analysis 21

5. METHODS AND PROCEDURES 23

  5.1 Survey Design 23
    5.1.1 Selection of First-Stage Sampling Units (FSUs) 25
    5.1.2 Selection of Second-Stage Sampling Units (SSUs) 29
      5.1.2.1 Selection of SSUs Within FSUs With Donnelley Listings 29
      5.1.2.2 Selection of SSUs Within FSUs With No Donnelley Listings 35
    5.1.3 Screening Response 36
    5.1.4 Selection of the Third Stage Sample 41
    5.1.5 Third Stage Response 46
    5.1.6 Variance Estimation and Screener Analysis ... 46

Table of Contents (continued)

Page

5.2 Survey Activities 48
- 5.2.1 Public Relations Efforts in Denver 48
- 5.2.2 Data Collection Instrument Development and Approval 49
- 5.2.3 Phase I - Household Screening Survey 49
  - 5.2.3.1 Computer Assisted Telephone Interviewing (CATI) System 50
  - 5.2.3.2 Telephone Interviewers 50
  - 5.2.3.3 Interviewing 51
- 5.2.4 Phase II - Washington, DC Area Survey 54
  - 5.2.4.1 Telephone Interviewing 54
  - 5.2.4.2 Final Document Preparation 57
  - 5.2.4.3 Protection of Human Subjects 57
  - 5.2.4.4 Field Staff Recruitment 57
  - 5.2.4.5 Training the Field Staff 58
  - 5.2.4.6 Field Office 58
  - 5.2.4.7 Special Field Studies 58
    - 5.2.4.7.1 Missed Housing Units 59
    - 5.2.4.7.2 Segments With No Donnelley Listing 59
    - 5.2.4.7.3 No Previous Telephone Contact 59
  - 5.2.4.8 Regular Field Assignments 59
  - 5.2.4.9 Breath Sampling 61

5.3 Field Measurements and Quality Assurance 62
- 5.3.1 Description of the Ambient Monitors 62
- 5.3.2 Description and Verification of the Field Standards 64
- 5.3.3 Preparation of CO Monitors for the Acquisition of a CO Exposure Sample 65
- 5.3.4 Analysis Method for Carbon Monoxide in Breath 73
  - 5.3.4.1 Description of Method 73
  - 5.3.4.2 Instrument Noise 74
  - 5.3.4.3 Instrumental Response Time 74
  - 5.3.4.4 Sample Bags - Recovery Study 77
  - 5.3.4.5 Sample Contamination from CBH Bags . 77
  - 5.3.4.6 Effect of Various Parameters on Breath CO Measurement 79
  - 5.3.4.7 Interference Due to Plastic Mouthpiece 83
  - 5.3.4.8 Effect of Concentrated Organic Compounds on Monitor and Prefilter Performance 83
  - 5.3.4.9 Method Precision 84
  - 5.3.4.10 Analysis Procedure Used During Field Sampling 84

Table of Contents (continued)

Page

5.4 Data File Creation and Descriptions 86
 5.4.1 Descriptions of Raw Data Files 86
 5.4.2 Creation of Analysis Files 97
  5.4.2.1 Creation of the Basic Analysis File (BAF) 97
  5.4.2.2 Creation of the Activity Analysis File (AAF) 102
  5.4.2.3 Creation of the Duplicate Measurement File (DMF) 110

6. RESULTS AND DISCUSSION 111

6.1 Survey Design Results 111
 6.1.1 Household Screener Statistical Analysis 111
 6.1.2 Personal Item Statistical Analysis 112
 6.1.3 Introduction to Sample Design Results 125
 6.1.4 Use of Geographically Classified Telephone Directory Listings in Association With Standard Area Household Sampling Techniques 125
 6.1.5 Lead Letter Results 134
 6.1.6 Sampling Person-Days 134

6.2 Field Survey Activities 136
 6.2.1 Survey Post-Field Activities 136
 6.2.2 Post Data Collection Discussions 139

6.3 Field Measurements and Quality Assurance 141
 6.3.1 Field Measurement Activities 141
  6.3.1.1 Personal Exposure Sampling 141
  6.3.1.2 Analysis of CO Levels in Respondent Breath Samples 144
  6.3.1.3 Fixed Site CO Data 144
 6.3.2 Problems With Monitors 146
  6.3.2.1 The COED-1 (GE/Magus) Monitor 146
  6.3.2.2 The GE/HP Monitor 158
 6.3.3 Quality Assurance Activities 161
  6.3.3.1 Quality Assurance Project Plan 161
  6.3.3.2 External (EPA-Conducted) QA Systems Audits 161
  6.3.3.3 Internal (RTI-Conducted) QC Audit .. 161
  6.3.3.4 Multipoint Calibrations to Assess Monitor Linearity 161
  6.3.3.5 Monitor Stability Over the Course of the Study 162
  6.3.3.6 Assessment of Measurement Precision and Accuracy 166

Table of Contents (continued)

Page

6.4 Results of Statistical Analysis 175
  6.4.1 Analysis of Hourly CO Exposure Data 178
  6.4.2 Analysis of CO Breath Measurements 193
  6.4.3 Analysis of Activities and Associated CO Exposures 193
    6.4.3.1 Activity and Location Patterns 195
    6.4.3.2 Carbon Monoxide Exposures 197
  6.4.4 Analysis of Measurement Variability 204

7. REFERENCES 209

APPENDIX A: Maps of Target Areas

APPENDIX B: Phase II Computer Model Input Questionnaire

APPENDIX C: Field Interviewer's Manual

APPENDIX D: Table of Contents of the OMB Package

APPENDIX E: Telephone Survey Unit Specifications

APPENDIX F: Phase II Telephone Interviewer's Manual

APPENDIX G: Materials on Protection of Human Subjects

APPENDIX H: Standard Operating Procedure for Collecting and Sampling Alveolar Carbon Monoxide

APPENDIX I: Quality Assurance Plan

APPENDIX J: Results of High and Low CO Exposure Days

APPENDIX K: High Occupational Exposure Categories

APPENDIX L: Post-Field Work Questionnaire

APPENDIX M: Comparison of COED-1 and Fixed Site Monitoring Data

LIST OF TABLES

Number	Title	Page
5.1.1	Distribution of Initial Telephone Screening Final Result Codes	32
5.1.2	Distribution of Final Result Codes for Denver Screening Sample	37
5.1.3	Distribution of Final Result Codes for Washington Screening Sample	39
5.1.4	Screening Response Rates	40
5.1.5	Third Stage Sample Allocation for the Denver Sample	42
5.1.6	Third Stage Sample Allocation for the Washington Sample	43
5.1.7	Distribution of Final Result Codes for Individuals Selected for CO Monitoring in Washington	47
5.3.1	Instrument Response Times in Minutes	76
5.3.2	Loss of CO From Fenwal Sampling Bags	78
5.3.3	Loss of CO From CHB Sampling Bags	78
5.3.4	Effect of Filter on Measured CO	80
5.3.5	Effect of Humid Air on Measured CO	80
5.3.6	Effect of Storage in Sampling Bags on CO Measurements at 3 ppm CO	80
5.3.7	Effect of Storage in Sampling Bags on CO Measurements at 7 ppm CO	81
5.3.8	Effect of Storage in Sampling Bags on CO Measurements at 15 ppm CO	81
5.3.9	The Effect of Ethanol on Measured CO	82
5.3.10	Breath Measurements for Non-Smoking Subjects	85
5.4.1	Number of Routine Samples With Valid Hourly CO Values, By Hour of Day	99

List of Tables (cont'd)

Number	Title	Page
5.4.2	Distribution of the Number of Hourly CO Values Per Sample	100
5.4.3	Distribution of Sampling Dates, by Month and Day of Week	100
6.1.1	Estimated Number of Households Using a Fireplace ...	113
6.1.2	Estimated Number of Households Using a Wood Stove ..	113
6.1.3	Estimated Number of Households Using a Gas Furnace .	114
6.1.4	Estimated Number of Households Using a Gas or Kerosene Space Heater	114
6.1.5	Estimated Number of Households Using a Gas Cooking Stove	115
6.1.6	Estimated Number of Households Using a Gas Hot Water Heater	115
6.1.7	Estimated Number of Households Using a Gas Clothes Dryer	116
6.1.8	Estimated Number of Households Using Other Gas Appliances	116
6.1.9	Estimated Number of Households Having an Attached Garage or Sharing a Multi-Family Garage	117
6.1.10	Estimated Sex Distribution	119
6.1.11	The Sex Distribution According to the 1980 Census ..	119
6.1.12	Estimated Age Distribution - Categorized According to the 1980 Census Definitions	120
6.1.13	Age Distribution According to the 1980 Census	121
6.1.14	Estimated Distribution of Relationship to Head of Household	122
6.1.15	Estimated Distribution of Persons 13 Years and Older Who Smoke or Use Tobacco in Any Form	123
6.1.16	Estimated Distribution of Persons 13 Years or Older Who Work Either Full or Part Time	126

List of Tables (cont'd)

Number	Title	Page
6.1.17	Estimated Distribution of Persons 13 Years or Older Who Travel Anywhere at Least 3 Times Per Week	126
6.1.18	Estimated Distribution of Amount of Time Spent Traveling One Way at Least 3 Times Per Week for Persons 13 Years or Older	127
6.1.19	Results of Missed HU Checks	129
6.3.1	Statistics on Ambient Sampling Waves	143
6.3.2	Results of Respondent Breath Analyses (ppm)	145
6.3.3	Site Characteristics of Washington Carbon Monoxide Monitors Operating During Study	147
6.3.4	Summary Statistics for Hourly Average Carbon Monoxide Values Reported by Washington Monitoring Sites Between November 8, 1982 and February 25, 1983	150
6.3.5	Date and Time of Maximum Hourly Average Carbon Monoxide Value	151
6.3.6	Summary Statistics for Daily Maximum 1-Hour Carbon Monoxide Values Reported by Washington Monitoring Sites Between November 8, 1982 and February 25, 1983	152
6.3.7	Summary Statistics for Daily Maximum 8-Hour Carbon Monoxide Values Reported by Washington Monitoring Sites Between November 8, 1982 and February 25, 1983	153
6.4.1	Estimates of Mean Population CO Exposure Levels (ppm) -- Diurnal Patterns by Time of Week and Type of Day	179
6.4.2	Summary of Maximum Hourly CO Concentration Data	182
6.4.3	Summary of Maximum 8-Hour CO Concentration Data	187
6.4.4	Summary of Mean Hourly CO Concentration Data	192
6.4.5	Summary of Breath CO Concentration Data	194

List of Tables (cont'd)

Number	Title	Page
6.4.6	Summary of Population Estimates Relating to the Number of Individuals Involved In, and Amount of Time Spent In, Various Types of Activities	196
6.4.7	Summary of Population Estimates Relating to the Number of Individuals Exposed To, and Amount of Time Spent In, Various Types of Environments	198
6.4.8	Summary of CO Exposure Levels, by Type of Activity	199
6.4.9	Summary of CO Exposure Levels, By Type of Activity -- Ranked According to Mean CO Level	200
6.4.10	Summary of CO Exposure Levels, by Type of Environment	202
6.4.11	Percentile Estimates of the Exposed Population CO Levels (ppm), By Type of Environment	203
6.4.12	Analysis of Replicate Hourly CO Concentrations	208

LIST OF FIGURES

Number	Title	Page
5.1.1	Selection of First-Stage Units and the Initial Sample of Donnelley Listings	28
5.1.2	Denver CO Sample Protocol	33
5.1.3	Washington CO Sample Protocol	34
5.2.1	Table of Contents of the Telephone Interviewer's Manual (CO Exposure Study)	52
5.2.2	Final Telephone Interviewing Status Report - Phase I Screening (Washington, DC and Denver, Colorado)	53
5.2.3	Telephone Response Rates	56
5.3.1	COED-1 Monitor Status Sheet	69
5.3.2	GE/HP Monitor Status Sheet	70
5.3.3	Field Data Sheet, Side 1	71
5.3.4	Field Data Sheet, Side 2	72
5.3.5	Instrument Noise	75
5.3.6	Breath Sample Data Sheet, Side 1	87
5.3.7	Breath Sample Data Sheet, Side 2	88
6.2.1	Carbon Monoxide Exposure Batch Header Sheet	138
6.3.1	Locations of Fixed-Site Monitors	149
6.3.2	Response Levels	163
6.3.3	Monitor Battery Voltages (volts)	164
6.3.4	Flow Rate	165
6.3.5	Washington, D.C. Personal CO Exposure Project PEM vs. Fixed Site Monitor (FSM) Comparison	168
6.3.6	Washington, D.C. Personal CO Exposure Project PEM vs. Fixed Site Monitor (FSM) Comparison: Plot of PEMCONC*FSM	170

List of Figures (cont'd)

Number	Title	Page
6.3.7	Washington, D.C. Personal CO Exposure Project PEM vs. Fixed Site Monitor (FSM) Comparison: PID=7000417	171
6.3.8	Washington, D.C. Personal CO Exposure Project PEM vs. Fixed Site Monitor (FSM) Comparison: PID=7000524	172
6.3.9	Washington, D.C. Personal CO Exposure Project PEM vs. Fixed Site Monitor (FSM) Comparison for Concentration Data ≥ 1.0 ppm	174
6.4.1	Average CO Exposure Levels, By Hour of Day	180
6.4.2	Maximum Hourly CO Concentrations by Occupational Exposure, Washington, D.C.	183
6.4.3	Maximum Hourly CO Concentrations for Weekdays and Weekend Days, Washington, D.C.	184
6.4.4	Maximum Hourly CO Concentrations for Selected Commuting Statuses, Washington, D.C.	185
6.4.5	Maximum 8-Hour CO Concentrations by Occupational Exposure, Washington, D.C.	188
6.4.6	Maximum 8-Hour CO Concentrations for Weekdays and Weekend Days, Washington, D.C.	189
6.4.7	Maximum 8-Hour CO Concentrations for Selected Commuting Statuses, Washington, D.C.	190
6.4.8	Plot of STDCONC * MEANCONC	205
6.4.9	Distribution of Standard Deviations of Replicate Observations	206

LIST OF EXHIBITS

Number	Title	Page
5.4.1	Contents of File A (PEM Data)	90
5.4.2	Description of Codes for Variables Appearing In File B (Activity Diary Data)	92
5.4.3	Contents of File D (Questionnaire Data)	94
5.4.4	Contents of Basic Analysis File	103

ACKNOWLEDGEMENTS

The authors would like to sincerely thank the following individuals for their assistance in carrying out the Carbon Monoxide Study: Dan Ward, John Sokash, and Jon Lodge of RTI who ran the field laboratory in Washington, D.C. and did an excellent job in maintenance and repair of the CO PEMs under severe time constraints; Velma Brock, Field Supervisor for the Washington, D.C. data collection effort; Martin Rosenzweig, Cliff Decker, Tom Virag, and Barbara Alexander of RTI and Robert Jungers of EPA who helped in many phases of the study including study design, data analysis, quality control, and project management; Lanny Piper and Janice Whelan who programmed RTI's computer assisted telephone interviewing system for the study; and Linda Sheldon who managed the experiments used to establish the breath analysis procedure. Without the aid of these individuals it would not have been possible to successfully carry out the project and we certainly appreciate their time and effort. Finally, we wish to express our appreciation to Ms. Carol Johnson for her excellent work in typing the manuscript.

ABSTRACT

This report describes a study funded by the EPA and conducted by the Research Triangle Institute in 1982 and 1983 to evaluate methodology for collecting representative personal exposure monitoring (PEM) CO and corresponding activity data in an urbanized area. This involved telephone screening of households and sample selection of respondents in the metropolitan areas in and around Denver, Colorado and Washington, D.C. Data on CO breath levels were also collected in Washington, D.C. (PEDCo Environmental conducted the field work in Denver.) The target population in both cities consisted of the non-institutionalized, non-smoking adults (ages 18 to 70) of these metropolitan areas. The data collected in the field were edited and appropriately weighted to produce CO exposure estimates for the target population. These estimates included average maximum hourly and 8-hour CO levels, and average CO levels for various activities and locations.

Based on the experience gained during the study, the methodology developed, with some modifications, may be used effectively in other areas of the country for collecting PEM data. These modifications should make the methodology more cost effective, improve the response rate, and lead to more accuracy activity information.

Estimates of CO exposure for the winter of 1982-83 in Washington, D.C. were obtained using the data base constructed from the raw CO levels by activity data which consisted of hourly CO values on 712 respondents, activity patterns and corresponding CO levels on 705 respondents, and CO breath measurements corresponding to the PEM CO data on 659 respondents. The size of the target population was estimated to be 1.22 million individuals.

The weighted average maximum hourly PEM CO level in Washington, D.C. was 6.74 ppm. The average maximum 8-hour CO level was 2.79 ppm. The percentage of the population with maximum hourly CO values over the 35 ppm CO standard was estimated to be 1.28 percent while the percentage with an 8-hour maximum over the 9 ppm standard was 3.9 percent.

Estimates were also made for subgroups of the population. Persons in high-exposure occupations (about 4.6% of the total population) generally exhibited higher CO exposure levels: it was estimated that about 24% of this high-exposure group had 1-hour CO exposures above the 35 ppm standard and that about 28% exceeded the 8-hour standard. It was also shown that CO levels were generally higher for commuters, especially for those with larger amounts of travel.

Breath CO levels (taken at the end of the sampling periods, usually in the respondents' homes) for the adult non-smoking population in Washington averaged 5.12 ppm. Slightly higher levels were observed for persons with high occupational exposures and for persons with large amounts of travel.

By combining PEM data with data from individuals' diaries, estimates of both CO levels and time durations for various activities and personal

environments were made. For example, the activities "in parking garage or parking lot" and "travel, transit" had the highest average CO concentrations (6.93 ppm, and 4.51 ppm, respectively) while "sleeping" had an estimated CO concentration of only .85 ppm. Among the environments considered, the three with the highest average CO concentrations were "indoor parking garage", "outdoor parking area", and "in transit-car". The average levels for these environments were 10.36, 4.67, and 5.05 ppm, respectively.

Variation from duplicate hourly PEM measurements under field condition were also analyzed. An analysis of variance of this data which considered person-to-person, hour-to-hour, and measurement variation indicated that about 5 to 6 percent of total variation among the hourly duplicate readings was due to deviation in measurements made by two PEMs at the same hour for the same person.

1. INTRODUCTION

As the control of emissions increases, the burden of proof on EPA to show that a particular level of emission control is justified also increases. It has become more and more important to show that a given level of control is justified for each air pollutant, with the relative risk of public health approximately comparable for each pollutant controlled.

A critical factor in determining the degree of risk to the population is the exposure of members of the population. In the past, monitoring of airborne pollutants has necessarily been based on the assumption that fixed-site monitoring is representative of concentrations surrounding the site, since monitoring techniques were generally not developed for determining personal exposures. Then to obtain estimates of population exposure, techniques such as computer simulation or overlaying isopleths of pollution concentrations measured at fixed sites on population density maps have been used. For some pollutants, these techniques may be reasonable approximations; however, recent work has shown that many pollutant concentrations are not homogeneous and that activity patterns play an important role in an individual's actual exposure. Therefore, data from ambient fixed sites often differ significantly from the concentrations with which people actually come into contact.

As EPA engages in modifications -- or "fine tuning" -- of emission standards, it becomes necessary to focus more attention on those components for which data are most lacking. The ultimate goal of the present research program was to develop a methodology to determine the public's exposure to air pollutants with known precision and accuracy.

A wide variety of air pollutants could have been selected for study. For example in the gas phase, carbon monoxide, nitrogen oxides, and hydrocarbons have been of concern either because they cause adverse health effects or because they are precursors in the formation of air pollutants that cause adverse health effects (e.g., ozone). In the solid phase, particulates and their associated organics have been targeted for control.

Carbon monoxide was selected for primary emphasis in the current study because:

- Accurate and portable field tested instruments now are available for CO (Wallace & Ott, 1982).
- Most of the CO to which the public is exposed can be attributed to motor vehicles.
- It appears that CO is a good "indicator" (i.e., surrogate) pollutant for estimating exposures to several other motor vehicle pollutants of interest.
- Because CO is a nonreactive air pollutant, it is simpler to treat analytically.
- The health effects of CO are reasonably well documented, and NAAQS based on these effects have been promulgated.
- Considerable data exist showing that CO varies spatially and that many locations in cities have concentrations that differ from those reported at fixed air monitoring stations.

Thus, RTI and EPA formulated a study plan to develop and field test a population exposure methodology using CO while making sure that the methodology was broad enough to accommodate other pollutants of concern. The specific objectives of this study were the following:

- To develop a methodology for measuring the distribution of carbon monoxide (CO) exposures of a representative population of an urban area for assessment of the risk to the population.
- To test, evaluate, and validate this methodology by employing it in the execution of pilot field studies in Denver, Colorado, and in Washington, DC.
- To obtain an activity-pattern data base related to CO exposures.

The study was carried out in Washington, DC and Denver, Colorado during the winter of 1982-83 (the period of the year with maximum ambient CO concentrations). The population exposure profile was determined by direct measurement of CO with personal exposure monitors (PEMs) through the use of statistical inference from the statistically drawn sample. The study provided sufficient data to determine exposure as a function of concentrations within significant microenvironments (home, in-transit, work, and leisure) and individual activity patterns.

The following report describes in detail the activities involved in this study and presents the results and recommendations evolving from the study. It is extremely important to note that the study not only developed and tested methodology for measuring the distribution of CO in an urban area but also produced direct estimates of CO exposure that apply to two large metropolitan areas. In addition, a very important product of this work is a unique and valuable data base on individual exposures to CO and the corresponding activities that led to these exposures.

2. SUMMARY OF STUDY DESIGN AND PROCEDURES

The study conducted by RTI was to evaluate methodology for collecting representative personal exposure monitoring (PEM) CO and corresponding activity data in an urbanized area. This involved telephone screening of households and sample selection of respondents in the metropolitan areas in and around Denver, Colorado and Washington, DC, and collection of PEM CO and activity data from respondents in Washington, DC. Data on CO breath levels were also collected in Washington, DC. (PEDCo Environmental conducted the field work in Denver.) The target population in both cities consisted of the non-institutionalized, non-smoking adults (ages 18 to 70) of these metropolitan areas. The data collected in the field were edited and appropriately weighted to produce CO exposure estimates for the target population. These estimates included average maximum hourly and 8-hour CO levels, and average CO levels for various activities and locations.

A probability sample of the target population was selected in both cities. This sample was a stratified, three-stage, probability-based design. Area sample segments defined by Census geographic variables were selected at the first stage of sampling. Households were selected at the second stage, and a household member was administered a short screening interview covering all household members to identify individuals with characteristics believed to be postively correlated with CO exposure. Thus, household members with these characteristics could be oversampled in the third stage. Donnelley Market Corporation listings were used to help select households for the screening interview. The third stage sample was a stratified sample of screened eligible individuals (i.e., non-smoking, aged 18 to 70). The individuals in the third stage sample were administered a Computer Model Input Questionnaire and were asked to carry a personal CO monitor and an Activity Diary for 24 or 48 hours (for Washington and Denver, respectively). A breath sample was also requested from these individuals and they were asked to fill out a Household (Study) Questionnaire. The third stage sample design also allocated individuals to specific days within the sampling period. A detailed discussion of the sample design is given in Section 5.1 and in Whitmore, et al. [1983a].

To carry out the sample design, RTI developed the data collection instruments and worked with EPA in obtaining OMB approval for the study. An initial telephone screening was carried out in both Denver and Washington, DC by using RTI's Computer Assisted Telephone Interviewing (CATI) system. This initial screening was supplemented by limited field screening in both sites. Specific information collected during this interview included: time spent in regular commuting and smoking status of each household member, as well as presence of gas appliances and attached garages in their residences. After the initial screening and the initial selection of potential participants, another telephone interview was conducted. The purpose of this call was to contact the selected individual to further explain the study and attempt to enroll him(her) into the study. If the individual agreed to be part of the study, an appointment was established for a field interview. In addition, during this call, a Computer Model Input Questionnaire was administered which collected additional data on commuting patterns, demographics of household members, and household characteristics.

Finally, participating individuals were met at their home or other convenient location and given all study materials. These participants carried both a PEM for the 24 hours of their participation and an Activity Diary in which to record a description of their activities. Participants were requested to push a button on their PEM every time they changed activities and to record descriptions of the new activities in their diaries. In addition, for a small sample of participants, a GE/HP PEM was used which allowed the participant to also enter an activity code into the monitor (see Section 5.3). Participants were also asked to complete a self-administered Household Questionnaire which provided information on themselves and on their home and work environments. The telephone screening and sample selection of individuals for both Denver and Washington were carried out by RTI as was the field work in Washington.

The results of the telephone screening and field activities for the study are described in detail in Sections 5.1 through 5.3. Briefly, 8643 household screenings were attempted by RTI in Washington, DC and 4987 were attempted in Denver, Colorado. The successful screening rates were 75.8 percent in Washington and 70.4 percent in Denver. From these telephone and field screenings, 5418 eligible respondents were identified in Washington and 2232 in Denver. From this population of eligibles, 1987 individuals were selected for participation (i.e., to carry a PEM) in Washington and 1139 in Denver. Of these selected individuals, 58 percent actually scheduled appointments to carry a PEM in Washington. Finally, 35.8 percent of the individuals in Washington selected to participate contributed usable CO monitor data. This represented 712 sample respondents. Instrument failure was one of the major reasons for the low response rate. Specifically, CO data was not collected or was unusable for analysis purposes for 232 respondents (22% loss rate) due to monitor failure or malfunction. Usable CO breath data corresponding to the usable CO monitor data was collected on 659 sample respondents.

In order to successfully implement the study in Washington, DC, a field office/laboratory was established in the offices of the Metropolitan DC Council of Governments. This office was used for several purposes including supervision of field staff, storage of supplies, maintenance of records, allocation of field assignments, and maintenance and repair of the PEMs. This office was visited twice nightly by all interviewers to receive PEMs and data collection forms for that evening and for return of completed study materials including the PEMs used the previous 24 hours. All calibrations of the PEMs during the study were carried out in this field laboratory. In addition to the field supervisor for the interviewers, the field laboratory was staffed with two full-time technicians working seven days per week throughout the study. A detailed description of the PEMs (COED-1s and GE/HPs) used in this study and the extensive daily technical support that they required is given in Section 5.3.

As mentioned above, breath samples were collected from respondents during the study. This required RTI to evaluate a method for collecting and measuring alveolar CO. This evaluation is described in detail in Section 5.3.4. The method essentially required each respondent to blow into a sample bag at the end of his 24 hour sampling period. This sealed bag was then returned to the field laboratory for CO analysis.

Throughout the field work, a quality control and assurance program was maintained for the sampling and analysis procedures employed (see Section 5.3 and 6.3). This included using field standards to calibrate all the CO monitors. The monitors were subject to calibration (two-point, zero/span) before they were put in the field and 24 hours later when they were returned from the field. The comparison of the two calibration curves was used to assign validity codes to the PEM data. Other quality control procedures employed were: a ten percent check of data transcribed from monitor memory to field data sheets; monitoring control charts on each monitor describing the course of differences between pre-sample and post-sample span, zero, battery voltage, and flow rate values; collecting duplicate colocated samples for the purpose of characterizing monitor precision; performing external and internal QA and QC audits; performing multipoint calibrations to assess monitor linearity during the study; and obtaining duplicate breath samples from respondents. The results of these extensive quality control and quality assurance procedures are given in Section 6.3.

After the field work was completed, the data were returned to RTI where detailed editing of the data was carried out by RTI editors. The data were then entered into computer files using RTI's mini-computer data base entry system. All data were keyed and then 100 percent key-verified. Extensive machine editing was carried out which resulted in identifying many computer records which required further manual editing. The process of editing the computer files took extensive staff time. In particular, checking the consistency of the PEM data with the diary data was a time consuming process.

Sampling weights were computed according to prescribed formulas (see Section 5.1). This involved extensive computations so that the weights could be used to draw inferences to the target populations. The sampling weights were then put on a computer file so that they could be merged with the corresponding field data.

Estimates were computed of household and individual characteristics in Washington and Denver using results from the Household Screening Questionnaire. When possible, these estimates were compared with corresponding Census estimates. Household estimates computed for the two areas included proportion of homes using a fireplace, a wood stove, a gas furnace, a gas cooking stove, and having an attached garage. Estimates computed for individuals' characteristics included age and sex distributions, proportion of smokers, proportion who work, and proportion who travel at least 3 times per week.

Detailed statistical analyses were carried out using computer data files with PEM CO and activity diary data (Section 6.4). Estimates computed during this analysis were weighted estimates for the population of inference - adult non-smokers in the Washington, DC metropolitan area. Standard errors of estimates were produced by using specially written software designed for analysis of data from complex sample surveys (see Shah [1981]).

In particular, analyses were first produced for hourly CO exposure data. These analyses included computing statistics describing diurnal patterns, maximum hourly CO concentrations, maximum 8-hour CO concentrations, and mean hourly CO concentrations. Statistics included means, standard errors, and percentages of the population exceeding certain specified CO levels. Estimates of these statistics were computed for all days, week and weekend days, and low and high CO days (as indicated by fixed site monitors). In addition, CO hourly level comparisons were also made for 3 occupational groups; 6 commuter group (i.e., non-commuters; commuters who traveled up to 5 hours/week; etc.); and 4 categories describing the use of gas stoves.

Estimates were also produced for CO exposure levels for various activities (e.g., in transit) and locations (e.g., indoors-at residence). Statistics computed for each activity and location included mean CO level, the estimated standard error, and estimates of the proportion of the population having CO levels above specified levels. The distribution of times spent in the various activities and locations were also computed.

Breath measurements taken at the end of each individuals' monitoring period were used to produce estimates of the distribution of CO breath levels in the Washington, DC area. Finally, using the duplicate CO monitor data, estimates were computed to assess variation in PEM measurements under field conditions.

3. SUMMARY OF STUDY RESULTS AND CONCLUSIONS

Based on the experience gained during the Washington, DC and Denver PEM CO studies, the methodology developed, with some modifications (see Section 4), may be used effectively in other areas of the country for collecting PEM data. Experience gained during this initial study will improve the execution of such similar studies. Modifications that are suggested include a different sampling design using the classified telephone directory listings, improvements in the CO monitors, and additional refinement of the method used to collect activity data. These modifications should make the methodology more cost effective, improve the response rate, and lead to more accurate activity information. However, it is important to realize that the response rates for a study of this complexity will always be relatively low as compared to studies where only a questionnaire is administered to a respondent. In particular, for the current study in Washington, DC, 58% of the individuals selected and interviewed over the telephone agreed to supply PEM CO data, and 35.8% actually gave analyzable CO data (see Sections 5.1 and 5.4 for additional details).

Important new information was learned for each of three sampling methodology studies of the project: (1) It was found that geographically classified telephone directory listings can be used in a cost-effective manner in association with standard area household sampling techniques for personal monitoring studies like the current CO study. The sampling design for the cost-effective use of these telephone directory listings differs substantially from the design used for the CO study, however (see required procedure in Sections 4 and 6.1). (2) Sending lead letters to individuals who were selected for personal monitoring prior to calling to schedule an appointment was found to be an effective strategy. (3) The need for person-day sampling for studies that monitor personal exposure to airborne pollutants is apparent. The CO study gained valuable experience with this technique. Further study, possibly even another methodological study, is needed to refine this technique (see Section 6.1).

Based on experience derived during this project, two important conclusions were reached concerning the use of the COED-1 and GE/HP monitors for monitoring personal CO exposure:

- The COED monitors exhibited a less than desirable reliability during this study producing a final successful sample completion rate of only 78 percent. Since most of the lost samples can be attributed to unreliability of the monitor electronics, the battery packs, or the sample pump (169 of the 232 samples lost due to monitor malfunction), these monitors will probably become acceptable for future projects of this type providing that the recommendations discussed in Sections 4 and 6.3.2.1 are successfully incorporated into the monitor design. Excessive calibration drift accounted for the remaining 63 of the 232 samples lost due to monitor malfunction (approximately 6 percent of the samples attempted). The monitors exhibited high linearity (calibration $r^2 \cong 0.9997$), acceptable stability (86 percent within ± 10 percent of initial response levels after 24 hours), and reasonable precision (median standard deviation of duplicate measurements ≅ 0.25 ppm) during field monitoring.
- The GE/HP monitors will probably be acceptable for such monitoring following perfection of the design and incorporation of the recommendations suggested in Sections 4 and 6.3.2.2. The full user-programmability of these monitors will add desirable flexibility, not achieveable with the COED-1, to future monitoring projects. On-board micro-processor monitoring of, and compensation for, parameters such as cell temperature and battery voltage may increase monitor stability and precision.

Concerning the monitoring of alveolar carbon monoxide by the method utilized during this project, the following conclusions were reached:

- The proposed method performed well, producing a mean difference between duplicate samples of 0.11 ppm ± 0.13 ppm at the

95 percent confidence level and an estimated accuracy of ± 0.3 ppm at 3.5 ppm and ± 1.0 ppm at 40 ppm. The proposed modification to the procedure concerning use of humidified zero and calibration matrices is, however, deemed necessary for procedural stability. The method is highly reliable (97.5 percent successful sample completion rate).

The field work for the study also indicated, in addition to the several suggested improvements in the present CO monitor and continued development of the autolog to record activities on the PEM, that other modifications can be made to enhance the reliability of the data collected and to ease the interviewer's work load for future PEM studies. These include: (1) devising a sampling scheme that will allow for down-time during data collection to permit instrument repair, enhance rescheduling of appointments, and provide regular time-off for field staff; and (2) allowing field staff earlier and fuller involvement in the development of logistical support mechanisms -- including monitor evaluation and testing, field laboratory space, and publicity (again, recommendations are given in Section 4).

Using the data collected in the Washington, DC and Denver metropolitan areas with the Household Screening Questionnaire, weighted estimates were computed of population characteristics (Section 6.1). These estimates were based on screening interviews in 4394 households in Washington and 2128 households in Denver. In particular, the population estimate for the number of households in the two areas was 953,714 for Washington and 345,163 for Denver. Population estimates of percentages of households with various characteristics were as follows:

	Washington	Denver
Use Fireplace	33%	30%
Use Wood Stove	4%	6%
Use Gas Furnace	56%	71%
Use Gas Stove	64%	25%
Use Gas Hot Water	57%	78%
Have Attached Garage or Multi-Family Garage	22%	35%

In addition to household characteristics, several estimates were also obtained for individuals' characteristics in the two areas. For example,

	Washington	Denver
Male	48%	47%
Smokers (13 years or older)	33%	38%
Work (13 years or older)	70%	72%
Travel ≥ 3 times/week	84%	82%

It is important to note the distribution of people selected for actual monitoring necessarily differs from the above in several ways. First, smokers were not sampled because they were ineligible for participation in the survey. Second, other population subgroups thought to be at risk for high CO exposure were oversampled. As discussed in Section 5.1.4, individuals with a usual daily commuting time of 30 minutes or more were oversampled. Individuals with a gas stove or space heater in the home were also oversampled, as were those with an attached garage. Thus, other population subgroups were relatively undersampled. The purpose of the oversampling was to insure representation of the population subgroups most likely to be exposed to high CO levels. This oversampling is compensated for in analysis of the CO data by use of the sampling weights. The sampling weights are inversely proportional to the probability of selection. Thus, the member of subgroups that were oversampled receive smaller sampling weights. As a result, weighted analyses produce unbiased estimates even when the subgroup sample sizes are not proportional to the number of population members in the subgroups.

Regarding estimates of CO exposure for the winter of 1982-83 in Washington, DC, a data base was constructed from the raw CO levels by activity data which consisted of hourly CO values on 712 respondents, activity patterns and corresponding CO levels on 705 respondents, and CO breath measurements corresponding to the PEM CO data on 659 respondents. These data were used to obtain estimates of CO exposure for the population of inference -- the adult (18 to 70 years old), non-smokers in the urbanized portion of the Washington, DC SMSA. The size of this population was estimated to be 1.22 million individuals. The results presented below are weighted estimates which apply to this population. Before analysis of the data could be undertaken, extensive editing was required of the raw data collected in the field (see Section 5.4).

The weighted average maximum hourly PEM CO level in Washington, DC was 6.74 ppm (this was computed as the weighted average of the maximum hourly CO value for each individual in the sample). The average maximum 8-hour CO level was 2.79 ppm. The percentage of the population with maximum hourly CO values over the 35 ppm CO standard was estimated to be 1.28 percent while the percentage with an 8-hour maximum over the 9 ppm standard was 3.9 percent.

Estimates were also made for subgroups of the population. Persons in high-exposure occupations (about 4.6% of the total population) generally exhibited higher CO exposure levels: it was estimated that about 24% of this high-exposure group had 1-hour CO exposures above the 35-ppm standard and that about 28% exceeded the 8-hour standard. It was also shown that CO levels were generally higher for commuters, especially for those with larger amounts of travel. For example, 8% of the commuters indicating 16 or more hours of travel per week were estimated to have maximum 8-hour CO concentrations over 9 ppm, whereas less than 1% of the non-commuters were estimated to have such levels.

Breath CO levels (taken at the end of the sampling periods, usually in the respondents' homes) for the adult non-smoking population in Washington averaged 5.12 ppm. Slightly higher levels were observed for persons with high occupational exposures and for persons with large amounts of travel.

By combining PEM data with data from individuals' diaries, estimates of both CO levels and time durations for various activities and personal environments were made. In general, these results were consistent with a priori expectations. For example, the activities "in parking garage or parking lot" and "travel, transit" had the highest average CO concentrations (6.93 ppm, and 4.51 ppm, respectively) while "sleeping" had an estimated CO concentration of only .85 ppm. Among the environments considered, the three with the highest average CO concentrations were "indoor parking garage", "outdoor parking area", and "in transit-car".

The average levels for these environments were 10.36, 4.67, and 5.05 ppm, respectively.

Variation from duplicate hourly PEM measurements under field conditions were also analyzed. An analysis of variance of this data which considered person-to-person, hour-to-hour, and measurement variation indicated that about 5 to 6 percent of total variation among the hourly duplicate readings was due to deviations in measurements made by two PEMs at the same hour for the same person.

4. RECOMMENDATIONS

The recommendations presented in this section suggest (1) improvements in the sample design and associated sampling procedures (e.g., the PEM); (2) changes in the logistics and methods of data collection for improving data quality and response rates; and (3) performing additional statistical analyses.

4.1 Design Recommendations

The suggested improvements in the sample design are described in detail in Section 6.1.4. Briefly, from RTI's experience using the geographically-classified telephone directory listings in the current CO study, it appears that such listings can best be utilized with a dual frame sampling procedure. In this approach, two independent samples of first stage units would be selected from the (complete) area frame: (1) one sample would be a standard area sample with sample clusters identified from field listings of all housing units in the selected area segments, (2) the other sample would use the commercial listings to identify sample clusters in the selected area segments. The commercial listing sample would only be used to generate telephone interviews based upon the telephone directory listing while the standard area frame sample would be used to compensate for the bias resulting from the telephone interviews generated by the commercial listing sample (see Section 6.1.4 for details on how the bias would be compensated for).

The lead letter methodology study (Section 5.1.4) indicated that these letters appeared to have had a positive effect upon response rates. Accordingly, in future studies, RTI would recommend that lead letters be sent to all individuals selected for monitoring. In this regard, it is important that the entire data collection methodology be further reviewed to determine other methods that might be used to increase response rates.

Some form of person-day sampling is necessary for future studies which monitor personal exposure during some time period. However, the procedure used in the current study (Section 5.1.4) was somewhat awkward. Therefore, a better procedure needs to be designed. One possible methodology would be to select six days within the study period for each person selected for monitoring. These could be three consecutive days in one week and the same three days in the next week. Priorities from one to six could then be assigned for each person. When the person is asked to participate, he would be asked to participate on his first priority day. If he could not participate then, the interviewer would proceed to the second priority day, etc. This methodology, or an alternative method, should be explored in future studies.

4.2 Recommendations Concerning Field Operations and Data Collection

As suggested in Section 3, there are several ways in which the field aspects of this study could be improved. These improvements would affect the willingness of individuals to participate, reduce the burden placed on respondents, and make the interviewer's job less difficult and time consuming. In general, the recommendations for change or improvement fall into three areas. These include: (1) the Carbon Monoxide (CO) Monitor and general data collection, (2) the sampling and field data collection process, and (3) logistical support.

Data Collection. Further development work must be done on both the CO monitors and the survey instruments used to collect data. When a respondent has agreed to participate and an appointment has been scheduled (sometimes with great difficulty), the loss of data due to instrument failure is quite distressing to the respondent and the field staff; moreover, the loss of data at an unpredictable and variable rate makes it extremely difficult to schedule field operations (e.g., to determine completion dates). The reliability of the CO monitor is thus extremely important to the results of a study of this type; therefore, further work must be done to improve the COEDs before they are used again in a full-scale field study.

Some specific problems with the two types of monitors used in this study, the COED-1 monitor and the GE/HP monitor, that need to be resolved before either monitor is used in the field for future studies are addressed below:

COED-1 Monitor

(1) The electronic problems with the Magus data unit of the COED-1 monitor must be corrected. Problems to be corrected are "lock-up", "mode shift", and susceptability to static discharge.

(2) Alkaline batteries should be considered as a substitute for the nickel-cadmium (Ni-Cd) batteries currently powering the CE-CO unit. Many of the battery related monitor failures were due to charging difficulties and reliability problems with the Ni-Cd batteries. Brief field tests indicated that six alkaline batteries will power the data unit for up to seven 24-hour sampling periods before replacement and four alkaline batteries will adequately power the CO monitoring unit for up to four 24-hour periods.

(3) A more durable sample pump, still compatible with monitor specifications, is necessary. The service life of the current pump may be as low as 900 hours.

(4) The configuration of the sample flow path should be modified so the flow through the prescrubber is up with respect to gravity to minimize the deposition of prescrubber material fines in the pump. If this is not possible, the scrubber should be horizontal. An efficient filter between the prescrubber cartridge and the pump may solve the problem if the filter can be easily replaced. Research has shown the filter will be quickly contaminated.

(5) The unit should have a sample pump on/off switch inaccessible to the respondent but available to the interviewer to reduce the load on the monitoring unit batteries.

(6) The electrical connection to the sample pump should be modified to facilitate removal and replacement of the pump because of the field requirements for frequent pump service. The connection currently requires soldering a piece of printed circuit tape to the pump motor terminals.

GE/HP Monitor

(1) The electronic design of the GE/HP monitor should be carefully examined and modified to eliminate the logic faults experienced during this project.

(2) The compatibility of the lead-acid gel cell batteries with the GE/HP unit should be investigated. Indications are that the batteries may not be capable of powering the currently designed unit for the necessary 28-32 hours.

(3) After the battery capacity question is decided, clear and complete instructions for charging the batteries must be written and charger/charging circuits of the appropriate capacity should be assembled and supplied to future users.

(4) The packaging of the GE/HP unit should be redesigned to combine the current two-component package.

(5) If batteries are to be removed from the GE/HP monitor for recharging, they should be made easier to access and remove. Also, battery connections should be polarized to prevent accidental reversal of polarity.

(6) The redesigned monitors should be thoroughly evaluated in the laboratory and in the field before they are used in another sampling project.

The rationale for these specific recommendations is further elaborated in Section 6.3.2.

In addition, further development and refinement of the capability to enter activities directly into the GE/HP monitor's data storage would yield benefits in at least two ways. The first would be the reduction in the number of steps involved in preparing data for analysis. The second would be higher quality information on activities, since more consistency from respondent-to-respondent would be attained. Since activity and exposure data would exist on the same data string, the problems associated with matching of data points by time, dealing with missing or inappropriate entries, and preparing analysis files would be ameliorated. Although the experience gained using the Hewlett Packard (HP) based COEDs was limited in time and numbers, the response of the persons who used the devices was very favorable. If the size of the keys and the printing of activities were enlarged, the instrument and the process of logging activities would be totally acceptable to respondents. In order to have more flexibility as to the number and types of permissible activities, a large detailed set of disjoint activities could be developed (based on data from this and other studies). Two-digit activity codes could then be assigned, and the HP programming could be modified to store and use the two-digit entry for such activities. After further development and testing, such a device might allow the use of the activity diary to be dropped or highly modified.

Review of the diaries indicated problems with legibility of respondents' entries and varying degrees of conformation to the specifications for entering activity and location information. In particular, diaries for later studies should be structured to force a standardized format for address entries. Further explanation by interviewers can address these problems, but a cost in time spent with respondents in a tightly scheduled field activity has definite impacts on the study. While modification of the diary format, instructions, and explanations may help, the best solution is the further development of the automatic entry of activity codes. A diary should be retained to provide quality control checks for the automatic logger, to test other concepts of data collection, and to provide detailed location (address) information.

Sampling and Field Data Processing. It is very difficult to maintain a field data collection process of the intensity of the CO study on a seven-day-per-week basis. The logistics required to start and finish individual respondents' data collection periods created extreme scheduling problems for both interviewers and respondents. It was very difficult to permit changes in respondents' appointments, even within a three day window, and it was exceedingly difficult to schedule time off for interviewers without compromizing the entire data collection process. Undoubtedly, a larger interviewing staff would aid the problem, but of course there would be an associated increase in costs. A review of the process of selecting respondents in terms of location and appointment availability might also yield some benefits by clustering work to provide increased efficiency and reduced expense.

Logistical Support. For future studies, it is recommended that the field staff who are to work in the laboratory and field office space be involved in the selection of the area to be used. For example, for a study similar in size and duration to the CO study, using similar monitoring equipment, approximately 500 square feet of office space would be needed. About 325 square feet would be used for the field technicians as a laboratory. The remaining 175 square feet would be used by the field interviewers for office and storage space. This space should be centrally located in the interviewing area with easy entry for staff members. Without this amount of space, the field staff and technicians will be hindered in performing their duties.

Another major concern is publicity. With the current climate of nonresponse to personal and telephone interview contacts, field data collections are increasingly difficult. Early and continued publicity on a project, with increased intensity at the beginning of each phase will help reduce non-participation by increasing awareness of the legitimacy of the study. A multi-media publicity drive before the telephone screening and before the appointment-scheduling telephone calls should be incorporated into further studies of this type. Use of lead letters before the final round of calls increased the response rate in the sample tested. Inclusion of a letter from the project sponsor would also be of benefit.

4.3 Recommendations for Further Statistical Analysis

Additional statistical analysis of the CO data over and above that presented in Section 6.4 should be undertaken. The data base developed by RTI and described in Section 5.4 is extremely rich and allows inferences to be made to a large urban area. In particular, possible additional analyses include the following:

(1) Statistical testing of differences between CO levels in various activities and environments using appropriate statistical software.

(2) Modeling maximum hourly and maximum 8-hour CO levels as functions of activities, environments, and questionnaire data (for these analyses, it may be desirable to control for individual characteristics, e.g., type of occupation).

(3) Comparing fixed-site and PEM values.

(4) Computing time-weighted CO levels (to take into account the time spent in an activity; e.g., the maximum 8-hour CO level is not highly affected by 15 minutes in a parking garage).

(5) Performing additional analysis of questionnaire data to determine the usefulness of specific questions.

(6) Examining in more detail relationships between CO levels and diary and questionnaire information (e.g., if occupationally-exposed individuals were actually working, etc.).

(7) Determining whether meteorological data are useful in predicting CO levels (analyses described in Section 6.4 only used high- and low-CO days; temperature, wind speed and direction, relative humidity, atmospheric stability, mixing height, and precipitation are also available).

(8) Correlating breath and PEM levels.

(9) Analyzing childrens' breath levels.

(10) Investigating between-person versus within-person variation.

(11) Analyzing data from the Computer Model Input Questionnaire.

(12) Presenting standard errors of estimated quantities (e.g., the proportions shown in Section 6.4).

5. METHODS AND PROCEDURES

5.1 Survey Design

The purpose of the carbon monoxide (CO) study was to develop methodology and to monitor personal exposure to carbon monoxide for residents of the metropolitan areas surrounding Denver, Colorado and Washington, D.C. The target populations consisted of the non-institutionalized, non-smoking residents, aged 18 to 70, of these metropolitan areas. For the purpose of sample selection, the Washington, D.C. metropolitan area was precisely defined to be all areas simultaneously inside the Washington, D.C. SMSA and inside the Washington, D.C. Urbanized Area as defined by the 1980 Census (see Appendix A). The Denver metropolitan area was defined to be the following places in Colorado as defined by the 1980 Census: Denver, Englewood, Arvada, Aurora, and Commerce City. These areas are also in the Urbanized Area of the Denver SMSA (see Appendix A).

Among the objectives of the CO study was to make inferences concerning the personal CO exposure for all members of the Denver and Washington metropolitan areas. The only statistically valid procedure that is widely accepted for making such inferences is to select a probability sample from the target populations. Hence, the sample design for the CO study is a stratified, three stage probability-based design. Area sample segments defined by Census geographic variables were selected at the first stage of sampling. Households were selected at the second stage, and all household members were administered a short screening interview. The purpose of this interview was to identify individuals with characteristics believed to be positively correlated with CO exposure so that they could be oversampled in the third stage sample. The third stage sample was a stratified sample of screened eligible individuals. The individuals in the third stage sample were administered a Computer Model Input Questionnaire by telephone (see Appendix B) and asked to carry a personal CO monitor for 24 or 48 hours for Washington or Denver, respectively. A breath sample was also requested from the individuals who were monitored, and they were asked to fill out a household questionnaire (see Appendix C).

Whenever probability sampling techniques are used in sample surveys, sampling weights that reflect the procedures used for sample selection must be used when analyzing the data. The weight of a sample unit can be viewed as the number of units in the target population that the sample unit represents. The initial sampling weight for a unit is usually calculated as the reciprocal of either the probability of selection of the unit or the expected frequency of selection when sampling with replacement. This initial sampling weight is often adjusted in later steps to reduce the bias caused by nonresponse and undercoverage of the target population. The adjusted sampling weights serve to differentially weight the sample data to reflect the level of disproportionality in the final sample relative to the population of interest.

If the sampling weights were all equal, the weights could be ignored in constructing survey estimates. Otherwise, the weights must be used in order to obtain unbiased population estimates. Even when the sample has been designed to affect exact proportional representation of the target population, the differential impact of nonresponse and undercoverage leads to a distortion in the sample which requires the construction of differentially adjusted sample weights. Thus, it would be quite unusual for sample survey data to yield unbiased estimates without the use of sampling weights in the analysis.

Since probability sampling techniques were used to select the individuals to be monitored, the validity of inferences for this survey is based upon the statistical theory of sample surveys (see, e.g., Cochran [1963] or Raj [1968]). Probability sampling affords unbiased inferences to the target population when sampling weights are used in the analyses.

To the extent that respondents and nonrespondents are alike with respect to probability of responding and/or response values within nonresponse weighting classes, the use of adjusted weights for the analyses reduces the bias due to nonresponse. This topic is discussed further in Whitmore, et al. [1983a].

Section 6.1.2 contains analyses of the screening data, including comparisons to 1980 Census data on age, race, and sex for the target areas. The Census data do not reflect changes in the populations of the target areas between April, 1980, and the Fall of 1982, when the CO study was performed. They do, however, provide a useful benchmark for comparison. The results presented in Section 6.1.2 show that the sample estimates and Census values are indeed comparable. No such benchmarks are readily available for the persons selected for CO monitoring since these individuals were required to be nonsmokers between 18 and 70 years of age. These benchmark comparisons are not necessary, however, due to the solid probability foundation of the sample selection methodology. The probability structure of the sample provides the basis for valid inferences to the target population.

The purpose of this section is to document the sample design and construction of sampling weights for the CO study. (Additional discussion of the sampling weights is also presented in Whitmore, et al. [1983a]). Initial, unadjusted sampling weights were computed for all individuals selected into the monitoring sample. These sampling weights are simply the reciprocal of the overall probability of selection for each individual. Two sets of adjusted weights have also been computed. The first set of adjusted person-level weights is adjusted only for household-level nonresponse to the screening interviews. The second set of adjusted weights is also adjusted for person-level nonresponse to the CO monitorings. Considerations related to use of these analysis weights are presented in Sections 5.1.5 and 5.1.6 and in Whitmore, et al. [1983a].

5.1.1 Selection of First-Stage Sampling Units (FSUs)

The first step in selecting the samples was to extract all block group (BG) and enumeration district (ED) records for each target area from the 1980 Census Summary Tape File 1A (STF-1A) data tapes. In both target areas, all Census records were found to be block group records. However, there is sometimes more than one record for a single block group. Hence, the next step was to produce a data set of records for each site such that there was one and only one record for each block group.

Since some block groups contain few, if any, occupied housing units as reported by the 1980 Census, it was necessary to combine block groups to form a sampling frame of first-stage units (FSUs). The block group records for each site were first ordered by the following Census geographic variables:

State, County, Tract Basic, Tract Suffix, Block Group.

The block groups were then combined within tract to form FSUs with a target size of 40 or more occupied housing units. The BG-level records were processed sequentially and records with a small size measure were combined with the following records until either the last BG record in a tract was reached or the frame unit contained 40 or more occupied housing units. The FSUs were not allowed to cross tract boundaries because of a desire to use sequential selection by tract number to assure geographic dispersion of the sample. In retrospect, the FSUs could have been allowed to cross tract boundaries without affecting the geographic dispersion of the sample. Each FSU would then contain at least 40 occupied housing units, and undercoverage of tracts with no 1980 Census occupied housing units would be prevented. None of the small frame units were actually selected into the samples, however.

In order to achieve approximately equal probabilities for the second-stage sampling units (SSUs) for each site, the first-stage sampling units were selected with probabilities proportional to size as measured by the 1980 Census counts of occupied housing units. Equal-sized random samples of SSUs within each FSU would then result in approximately equal probabilities for the sample of SSUs.

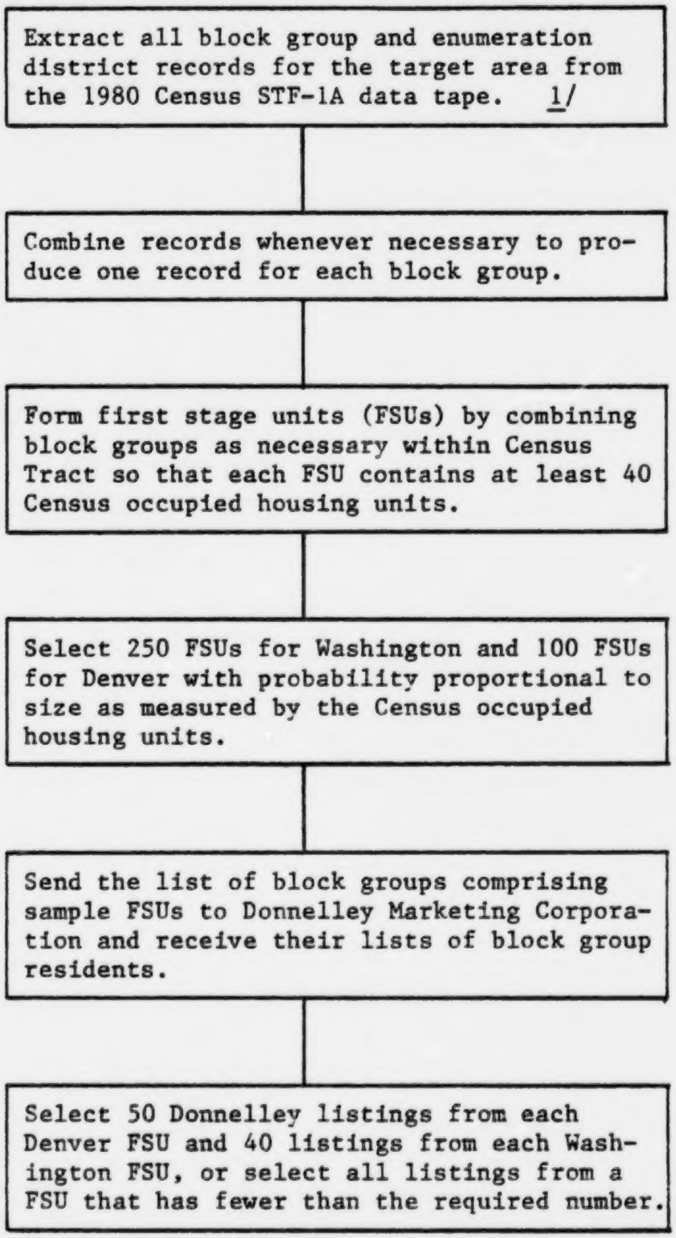
A sequential, minimum probability replacement (MPR) sampling procedure developed at RTI was used to select the sample of FSUs (See Chromy [1979] and Williams and Chromy [1980]). The frame for each site was first ordered in a serpentine fashion by the following variables:

State, County, Tract, TOTHUS,

where TOTHUS is the number of 1980 Census occupied housing units for the FSU. The FSUs were then selected with probabilities proportional to size as measured by TOTHUS from the ordered sampling frame. The sample sizes were 250 FSUs for Washington and 100 for Denver. Since the sampling was performed with replacement, multiple selections of the same FSU were possible. One FSU in the Denver sample was selected twice, so the Denver sample contains 99 distinct FSUs or area sample segments. The sample for Washington consists of 250 distinct FSUs or area segments. In addition, the ordering of the sampling frames resulted in a controlled allocation (proportional allocation) to the implicit geographic strata formed by crossing the sorting variables. This control results from the sequential nature of the sample selection and is analogous to selection of a systematic sample from an ordered frame.

After the sample FSUs were selected, a computer tape listing the block groups (BGs) in the sample FSUs was sent to Donnelley Marketing Corporation. The tape was returned to RTI with name, address, and telephone number listings for each sample BG. The first-stage sample selection and selection of the initial sample of Donnelley listings is summarized by the flow chart in Figure 5.1.1.

The Donnelley listings had been compiled from two sources: telephone directory listings and vehicle registration records. Ideally, the number of Donnelley listings for a BG should be comparable to the 1980 Census of occupied housing units for the BG. The Donnelley list count and the Census count were comparable for most BGs. Unfortunately, however, three FSUs in the Washington sample had no Donnelley listings. These three FSUs were in an area of Maryland for which the Donnelley Corporation had no telephone listings, and Maryland does not allow the Donnelley Corporation access to its vehicle registration records. For all other FSUs, the Donnelley lists were used as the second-stage sampling frames.



Extract all block group and enumeration district records for the target area from the 1980 Census STF-1A data tape. [1]

Combine records whenever necessary to produce one record for each block group.

Form first stage units (FSUs) by combining block groups as necessary within Census Tract so that each FSU contains at least 40 Census occupied housing units.

Select 250 FSUs for Washington and 100 FSUs for Denver with probability proportional to size as measured by the Census occupied housing units.

Send the list of block groups comprising sample FSUs to Donnelley Marketing Corporation and receive their lists of block group residents.

Select 50 Donnelley listings from each Denver FSU and 40 listings from each Washington FSU, or select all listings from a FSU that has fewer than the required number.

---

[1] All extracted records were block group records.

Figure 5.1.1 Selection of First-Stage Units and the Initial Sample of Donnelley Listings.

5.1.2 Selection of Second-Stage Sampling Units (SSUs)

A second-stage sample of housing units, as defined for the 1980 Census, was selected within each sample FSU. For the FSUs with Donnelley listings, the Donnelley listings were used to select the second-stage sample. The listings were used as a second-stage sampling frame in lieu of the traditional field listing of all housing units in the sample segments. For the three Washington FSUs with no Donnelley listings, field procedures were used to select second-stage samples of housing units.

5.1.2.1 Selection of SSUs Within FSUs With Donnelley Listings

For each FSU with Donnelley listings, a simple random sample of listings was selected without replacement. A random sample of 50 listings was selected within each Denver FSU, and 40 within each Washington FSU. For any FSU that did not contain this many listings, all listings were selected. A sample of 9,876 listings was selected for Washington, and 4,987 listings were selected for the Denver sample. When it became apparent that a smaller sample size would produce sufficient screening data for Washington, the Washington sample was randomly subsampled. The utlimate sample size for Washington was 8,643 listings. Whitmore, et al. [1983a] discusses the computation of the first stage sample weights using the above scheme.

In order to obtain complete coverage of the target population, the sample of Donnelley listings was regarded as a sample of housing units identified by the name and address in each Donnelley listing. There were many Donnelley listings for which the address alone was not sufficient to identify a specific housing unit. This was particularly true of housing units in apartment complexes. Since most Donnelley listings come from telephone directory listings, the address shown for apartment residents was often no more than the street address of the apartment complex. Whenever the address was not sufficient to identify a particular housing unit, the individual's name was also used. The sample housing unit was then defined to be the housing unit at the sample address in which the named individual either currently or previously resided.

A single housing unit also may be linked to more than one Donnelley listing. This can occur whenever the Donnelley Corporation listed multiple telephone subscribers and/or vehicle registrants for a single housing unit. These frame multiplicities can be associated with current residents of the housing unit and/or previous residents of the housing unit. Since the name and address must sometimes be used simultaneously to identify a sample housing unit, it is virtually impossible to accurately identify all of these frame multiplicities. Consequently, no attempt was made to remove these multiplicities from the sampling frame prior to sample selection. It also does not appear to be cost-effective to pursue any multiplicity adjustments in analysis of this sample. Hence, the sampling weights have been computed treating each sample housing unit as if it was linked to only one Donnelley listing.

All sample Donnelley listings were initially assigned to the telephone mode for administration of the screening interview. About 75 percent of the sampled Denver listings and about 88 percent of the sampled Washington listings had phone numbers. The difference seems to be that vehicle registration records were not available to Donnelley Corporation for the Maryland portion of the Washington sample, but were available for all of Colorado. RTI's telephone interviewing staff attempted to obtain telephone numbers for the sample listings with no phone number. Phone numbers were obtained for about ten percent of these listings.

For each call made by the telephone interviewing staff, the telephone number was first verified with the individual who answered. If the correct telephone number had been reached, the address was also verified. Since the sample was regarded as an address sample, not a telephone number sample, the interview was terminated if the individual's address was not the address shown for the sample Donnelley listing. These addresses were placed in a pool to be subsampled for field interviewing. Otherwise, all individuals living in the housing unit (1980 Census definition) were screened by a telephone interview. The name shown for the Donnelley listing was never verified. It was implicitly assumed that the correct housing unit had been accessed if the telephone number and address were correct.

Table 5.1.1 presents the final result codes generated by the telephone screening attempts. It also identifies a pool of result codes for which the listings were treated as not covered by the telephone screenings, e.g., those for which no phone number could be obtained. Some assumptions are inherent in this categorization. For example, it has been assumed that listings with a final result of "ring-no-answer" are listings for which the address would have been verified as correct if someone had been contacted. The distribution of the telephone result codes is also presented in Table 5.1.1.

It was not feasible with the project's time and money constraints to attempt field screenings for all sample Donnelley listings not covered by the telephone screenings. Hence, a subsample of these listings was selected as illustrated by the subsample of n_2 Donnelley listings shown in Figures 5.1.2 and 5.1.3. Given the sampling rates shown in Figures 5.1.2 and 5.1.3, the loss in precision due to this subsampling is considered acceptable. A field interviewer was sent to each housing unit represented by this subsample of Donnelley listings. The field interviewer administered the screening interview if a reliable respondent was available on the first attempt. Otherwise, the interviewer attempted to get the correct telephone number from a neighbor or information operator. When the field interviewer was able to get a telephone number for the sample housing unit, subsequent screening attempts were made by telephone. When the first attempt did not yield either a completed interview or a telephone number, additional field attempts were made for the Denver sample. The wide geographic dispersion of the Washington sample made additional field attempts prohibitively expensive for the Washington sample.

As shown in Figure 5.1.2, a total of 1,825 sample Donnelley listings were not covered by the initial telephone screenings for Denver. A simple random sample of 242 of these listings was selected without replacement. A field screening attempt was made for each listing in this subsample. Similarly, as shown in Figure 5.1.3, a simple random sample of 353 listings was selected without replacement from 2,396 sample listings not covered by the initial telephone screenings for Washington.

Table 5.1.1 Distribution of Initial Telephone Screening Final Result Codes

Result Code	Interpretation	Frequency Denver	Frequency Washington
01	Completed Interview	1,997	4,245
51	Refusal or Breakoff, Conversion Attempt Failed	469	673
52	Refusal or Breakoff, Not Reached for Conversion Attempt	135	93
53 1/	Circumstantial Non-Interview	6	10
64 2/	Partial Interview	13	32
71 3/	Nonworking Number	436	997
72	Nonresidential Number	91	187
73	Entire Household Moving	92	187
74 3/	Address Doesn't Match Donnelley Listing	350	609
75	No Reliable Respondent (3 attempts)	21	36
76 3/	No Phone Number	1,032	782
81 3/ 4/	Final Phone Problem (confirmed by operator)	7	8
82	Ring-No-Answer (6 attempts)	207	503
83	Answering Machine (6 attempts)	22	35
84	Final Busy (10 attempts)	4	4
95	Other (both eligible & ineligible cases)	105	242
Total		4,987	8,643

1/ An eligible housing unit was contacted, but circumstances prevented a screening interview.

2/ Breakoff after Question 7.

3/ Result Codes for the pool of Donnelley listings not covered by the initial telephone screening.

4/ Branching, complete silence, fast-busy or other problem confirmed by an Operator.

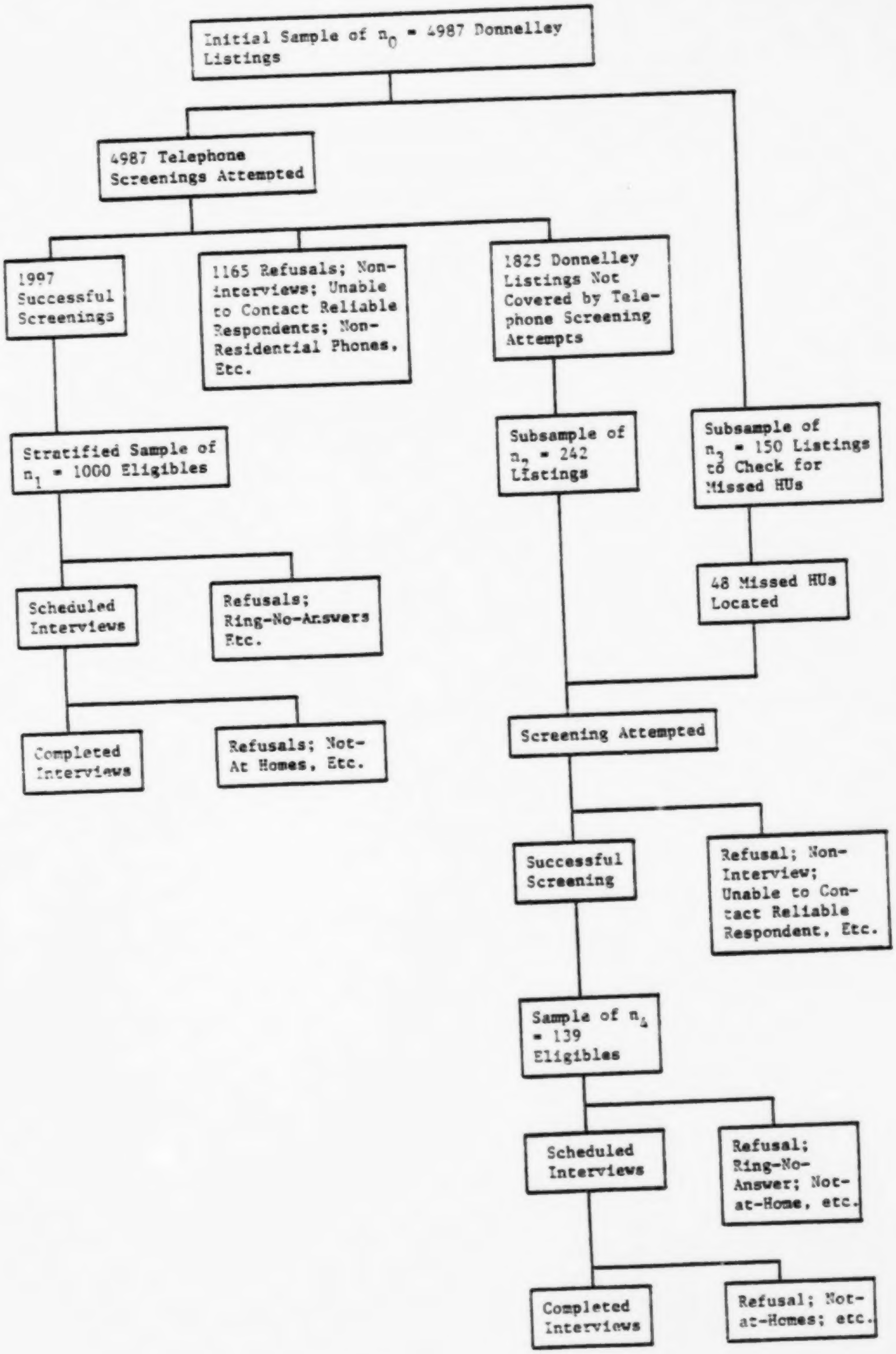
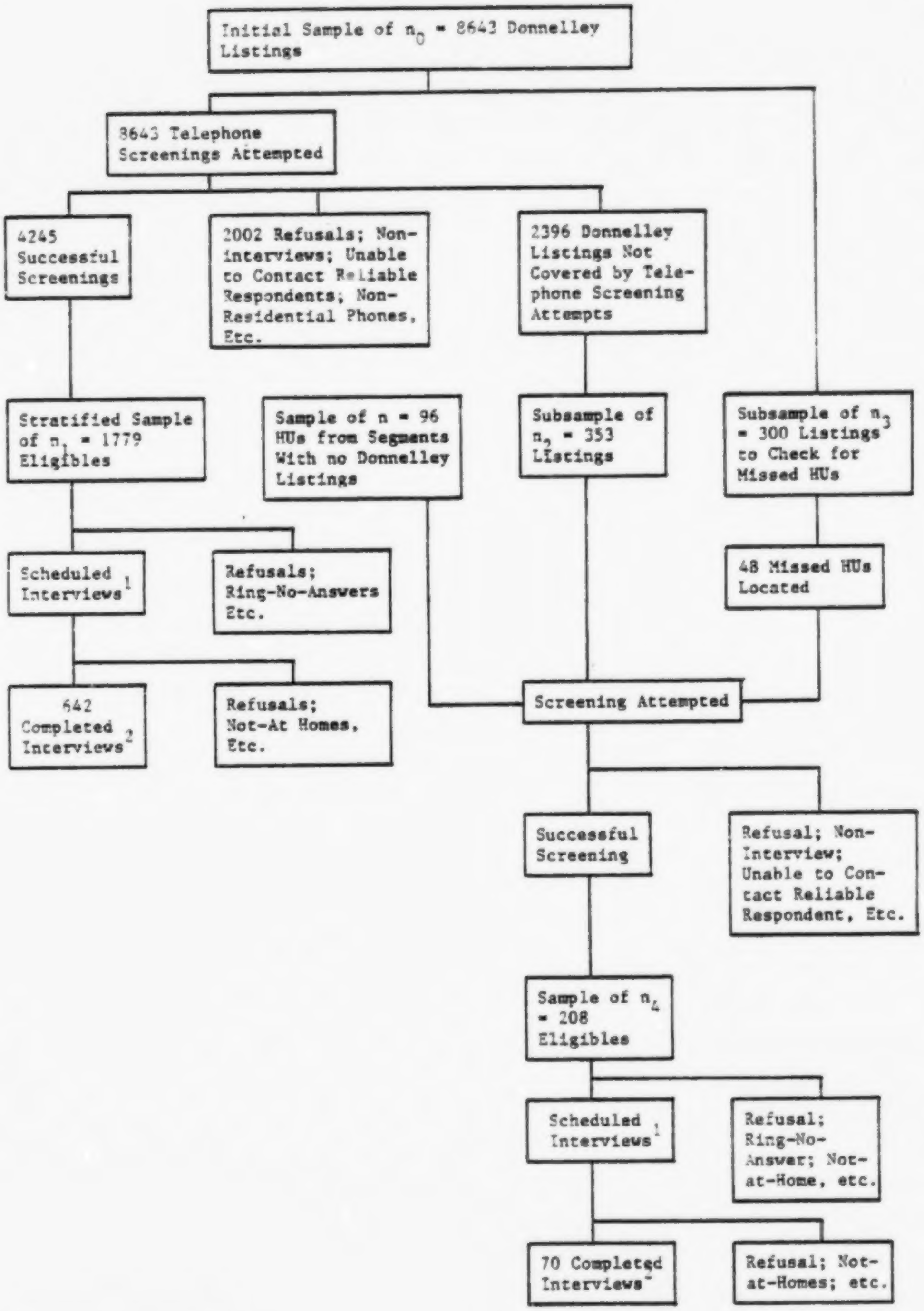

Initial Sample of n_0 = 4987 Donnelley Listings
4987 Telephone Screenings Attempted
1997 Successful Screenings
1165 Refusals; Non-interviews; Unable to Contact Reliable Respondents; Non-Residential Phones, Etc.
1825 Donnelley Listings Not Covered by Telephone Screening Attempts
Stratified Sample of n_1 = 1000 Eligibles
Subsample of n_2 = 242 Listings
Subsample of n_3 = 150 Listings to Check for Missed HUs
Scheduled Interviews
Refusals; Ring-No-Answers Etc.
48 Missed HUs Located
Completed Interviews
Refusals; Not-At Homes, Etc.
Screening Attempted
Successful Screening
Refusal; Non-Interview; Unable to Contact Reliable Respondent, Etc.
Sample of n_4 = 139 Eligibles
Scheduled Interviews
Refusal; Ring-No-Answer; Not-at-Home, etc.
Completed Interviews
Refusal; Not-at-Homes; etc.

Figure 5.1.2 Denver CO Sample Protocol


Initial Sample of n0 = 8643 Donnelley Listings
8643 Telephone Screenings Attempted
4245 Successful Screenings
2002 Refusals; Non-interviews; Unable to Contact Reliable Respondents; Non-Residential Phones, Etc.
2396 Donnelley Listings Not Covered by Telephone Screening Attempts
Stratified Sample of n1 = 1779 Eligibles
Sample of n = 96 HUs from Segments With no Donnelley Listings
Subsample of n2 = 353 Listings
Subsample of n3 = 300 Listings to Check for Missed HUs
Scheduled Interviews1
Refusals; Ring-No-Answers Etc.
48 Missed HUs Located
642 Completed Interviews2
Refusals; Not-At Homes, Etc.
Screening Attempted
Successful Screening
Refusal; Non-Interview; Unable to Contact Reliable Respondent, Etc.
Sample of n4 = 208 Eligibles
Scheduled Interviews1
Refusal; Ring-No-Answer; Not-at-Home, etc.
70 Completed Interviews2
Refusal; Not-at-Homes; etc.

---

[1] A total of 1217 interviews were scheduled between all Washington samples.
[2] Usable CO monitor data were obtained for 712 individuals in the Washington samples.

Figure 5.1.3 Washington CO Sample Protocol

The second-stage sample of housing units also addressed the problem of undercoverage by the frame of Donnelley listings. In a traditional listing of all HUs in the sample segments, the interval from each sample housing unit (HU) to the next listed HU is checked for missed HUs. If unlisted HUs are found, they are included in the sample. The direct extension of this procedure to the sample of Donnelley listings would require a check for missed HUs for each of the 8,643 Washington sample HUs and each of the 4,987 Denver sample HUs. This procedure was not feasible since most of the screening interviews were conducted by telephone. Instead, a subsample of Donnelley listings to check for missed HUs was selected for each site. The subsample of n_3 HUs, using the notation from Figure 5.1.2, was selected in two stages. First, a subsample of FSUs was selected, 15 for Denver and 30 for Washington. Then a subsample of ten Donnelley listings from the initial sample of n_0 Donnelley listings was selected by simple random sampling without replacement from each of these area segments. The FSUs were selected as a stratified simple random sample without replacement. This stratification was designed to guarantee that some of the missed HU sample would fall within the segments for which the number of 1980 Census occupied housing units was 50 percent or more greater than the number of Donnelley listings.

The sample of Donnelley listings for which a missed HU check was performed is considered to be minimally adequate. A larger sample was not selected because the expense of the missed HU checking depended upon the unknown quality of the Donnelley listings. The missed HU field procedure was designed to also detect and document misclassifications of HUs into block groups. Hence, the Missed HU Sample was important for assessing the usefulness of the Donnelley listings as a sampling frame. As a result, it was decided that a thorough check in a few FSUs was the best approach. The results of these checks were generally favorable and are discussed in Section 6.1.4.

5.1.2.2 Selection of SSUs Within FSUs With No Donnelley Listings

As discussed earlier, there were three FSUs in the Washington sample for which there were no Donnelley listings. Sample housing units were selected from these FSUs even though no funds were budgeted for field listing of housing units in area segments. Hence, a minimal cost procedure that affected complete coverage of these FSUs was adopted. Block statistics from Summary Tape File 1B (STF-1B) were used to obtain the 1980 Census count of occupied housing units for each block within these FSUs. The blocks were then combined into subsegments and one subsegment was selected from within each FSU. The subsegments were selected with probabilities proportional to their 1980 Census count of occupied housing units. Thus, approximately equal sized samples within the subsegments were selected to obtain an approximately equally weighted sample.

Since the budget for field screenings was very limited, the field samples were selected without listing all housing units. Instead, every k^{th} HU was selected into the sample, with a random start from 1 to k. The value of k was chosen to yield approximately 35 sample housing units in each subsegment based upon the 1980 Census data. The only compromise resulting from this procedure is that direct quality control of the listing became impractical. However, as an alternative, these samples were listed by one of RTI's most experienced and reliable field staff members. We feel that the quality of the listing was probably superior to the qualilty usually achieved with the standard procedures.

If a reliable respondent was available on the first pass through each subsegment, a screening interview was conducted. If the field interviewer could get the home telephone number, subsequent screening attempts were made by telephone from RTI. Otherwise, the budget permitted no further interview attempts. Further discussion of the special subsample is presented in Whitmore, et al. [1983a].

5.1.3 Screening Response

The distribution of final result codes for the Denver and Washington screening samples is shown in Tables 5.1.2 and 5.1.3. The overall response rates for the screening phase, shown in Table 5.1.4, were 70.4 percent for Denver and 75.8 percent for Washington. The sample design proposed in Section 6.1 is expected to raise these response rates to near 80 percent for future studies of this type.

Table 5.1.2 Distribution of Final Result Codes for Denver Screening Sample

Result Code	Interpretation	Primary Phone Screenings	No Previous Contact	Missed HUs	Total
01	Completed Interview/ Telephone Number Obtained	1,997	109	27	2,133
02	Completed Interview/ Telephone Number Not Obtained	0	0	0	0
03	Completed Interview/ No Telephone Available	0	0	0	0
05	Entire Household Moving Based on Field Contact	0	6	0	6
11	No Age Eligible During Field Contact/Telephone Number Obtained	0	0	0	0
14	No One Home During Field Contact/Telephone Number Not Obtained	0	0	0	0
17	Language Barrier/ Telephone Number Obtained	0	4	1	5
18	Language Barrier/ Telephone Number Not Obtained	0	1	0	1
20	Field Refusal/ Breakoff	0	22	8	30
25	No Contact	0	29	12	41
30	Not a Residence	0	8	0	8
31	Vacant	0	6	0	6
32	Demolished/Condemned	0	3	0	3
33	No Such Address	0	11	0	11
40	Other Field Result	0	43	0	43

continued

Table 5.1.2 continued

Result Code	Interpretation	Primary Phone Screenings	No Previous Contact	Missed HUs	Total
51	Refusal or Breakoff Conversion Attempt Failed	469	0	0	469
52	Refusal or Breakoff Not Reached for Conversion Attempt	135	0	0	135
53	Circumstantial Non-Interview	6	0	0	6
64	Partial Interview	13	0	0	13
71	Nonworking Number	0	0	0	0
72	Nonresidential Number	91	0	0	91
73	Entire Household Moving	92	0	0	92
74	Address Doesn't Match Donnelley Listing	0	0	0	0
75	No Reliable Respondent (3 attempts)	21	0	0	21
82	Ring-No-Answer (6 attempts)	207	0	0	207
83	Answering Machine (6 attempts)	22	0	0	22
84	Final Busy (10 attempts)	4	0	0	4
95	Other (both eligible and ineligible cases)	105	0	0	105
TOTAL		3,162	242	48	3,452

Table 5.1.3 Distribution of Final Result Codes for Washington Screening Sample

1/ Result Code	Primary Phone Screenings	No Previous Contact	Missed HUs	No Donnelley Listings	Total
01	4,245	85	15	56	4,401
02	0	2	1	2	5
03	0	0	0	2	2
05	0	2	0	0	2
11	0	0	1	0	1
14	0	9	1	0	10
18	0	1	0	0	1
20	0	29	3	10	42
25	0	49	17	15	81
30	0	8	0	0	8
31	0	19	0	1	20
32	0	5	0	0	5
33	0	7	0	0	7
40	0	38	6	0	44
51	673	0	0	1	674
52	93	0	0	0	93
53	10	0	0	0	10
64	32	3	0	5	40
71	0	5	0	0	5
72	187	1	0	0	188
73	187	0	1	0	188
74	0	27	0	3	30
75	36	1	0	0	37
82	503	2	1	0	506
83	35	1	0	0	36
84	4	0	0	0	4
95	242	59	0	1	302
Total	6,247	353	46	96	6,742

1/ See Table 5.1.2 for result code description.

Table 5.1.4 Screening Response Rates 1/

Sample	Denver	Washington
Initial Telephone Screenings	0.720	0.791
No Previous Contact Sample	0.524	0.282 2/
Missed HUs	0.563	0.364 2/
No Donnelley Listings	NA	0.632 2/
Overall	0.704	0.758

1/ Response rate calculation in terms of final result codes from Table 1.7:

$$\text{Rate} = \frac{01 + 02 + 03}{\text{Total} - 05\text{-}30\text{-}31\text{-}32\text{-}33\text{-}72\text{-}73\text{-}82}$$

2/ Field screening response rates are low for Washington because the field effort was minimized to control costs. Due to the wide geographic dispersion of the Washington field sample, a more exhaustive field effort was considered to be prohibitively expensive.

Nonresponse adjustment to the sampling weights are discussed in Whitmore, et al. [1983a] including the formation of weighting classes.

5.1.4 Selection of the Third Stage Sample

As discussed in Section 5.1, the eligible individuals for the CO study were the nonsmoking residents of the target areas between 18 and 70 years of age. The field screenings yielded 139 eligible individuals in responding households for the Denver samples and 214 eligible individuals for the Washington samples. The field screenings were generated by the No Previous Contact Sample and the Missed HU Sample for Denver. They also included the sample for the three area segments with no Donnelley listings for Washington. All eligible individuals from the Denver field samples were selected into the third stage sample for CO monitoring. For Washington, the 208 eligible individuals with a known telephone number were all selected for CO monitoring.

The initial telephone screenings yielded 2093 eligible individuals for Denver and 5209 eligible individuals for Washington. For each site, a stratified simple random sample of eligible individuals was selected for CO monitoring as shown in Tables 5.1.5 and 5.1.6. The purpose of the stratification was to oversample those individuals who appeared likely to be exposed to the highest CO levels based upon their screening data. Since the sample sizes defined by Tables 5.1.5 and 5.1.6 were not explicitly allocated to first-stage sampling units, the number of sample individuals selected from each first-stage unit is actually a random variable. Hence, the sample design is not strictly a nested design, which presents some problems for estimation of precision, as discussed in Whitmore, et al. [1983a].

The sample stratification for the initial telephone screenings is shown in Tables 5.1.5 and 5.1.6. The strata are defined in terms of four stratification variables. Based upon discussions with EPA staff members, it was decided that commuting time was the most important stratification variable. Respondents who had indicated a usual daily one-way commuting time of 30 minutes or more were defined as belonging to the "long commuting time" strata. All other respondents were defined to belong to the "short commuting time" strata. It was decided that the

Table 5.1.5 Third Stage Sample Allocation for the Denver Sample

Stratum Number	Commuting Time	Gas Appliance	Attached Garage	Screened Eligibles	Sample Size
1	Short	Space Heater	Yes	48	48
2	Short	Space Heater	No	43	43
3	Short	Gas 1/ Stove	Yes	70	56
4	Short	Gas Stove	No	342	148
5	Short	Other	Yes	529	229
6	Short	Other	No	577	250
7	Long	Space Heater or Gas Stove	--	143	74
8	Long	Other	Yes	182	78
9	Long	Other	No	159	74
TOTALS				2,093	1,000

1/ Gas stove, but not a space heater.

Table 5.1.6 Third Stage Sample Allocation for the Washington Sample

Stratum Number	Commuting Time	Gas Appliance	Attached Garage	Smoker in HU	Screened Eligibles	Sample Size	Lead Letter
1	Short	Space Heater	--	--	124	66	22
2	Short	Gas 1/ Stove	Yes	--	162	66	22
3	Short	Gas Stove	No	Yes	447	143	48
4	Short	Gas Stove	No	No	1085	346	116
5	Short	Other	Yes	--	443	143	48
6	Short	Other	No	--	840	271	91
7	Long	Space Heater	--	--	94	66	22
8	Long	Gas Stove	Yes	--	105	66	22
9	Long	Gas Stove	No	Yes	295	94	31
10	Long	Gas Stove	No	No	730	233	78
11	Long	Other	Yes	--	286	94	32
12	Long	Other	No	--	598	191	64
TOTALS					5209	1779	596

1/ Gas stove, but not a space heater.

second most important stratification variable was a gas applicance variable. This variable was defined to have the following levels in terms of the gas appliances used at the respondent's residence:

(a) a space heater is used,
(b) a gas stove is used, but not a space heater, or
(c) neither space heater nor gas stove is used.

The screening questionnaire had probed for use of several types of gas appliances in the residence. It was decided that all types of gas appliances other than space heaters and gas stoves were usually vented. Hence, space heaters and gas stoves were considered the major sources of CO generation within the home and were used for stratification. Rare groups based upon these two stratification variables were oversampled, and the remainder of the sample was proportionally allocated to the remaining strata for each site. Some of the larger strata that received a proportional allocation of the remaining sample were divided into substrata. Since the substrata received a proportional allocation, the additional stratification simply added control over distributional characteristics of the sample.

Two additional variables were used to define substrata: Presence of an attached garage and use of tobacco in the home. Individuals in households that indicated an attached garage were assigned to one level of the attached garage variable, and all other individuals were assigned to a second level. The individuals from a residence in which someone was identified as a tobacco user were assigned to one level of the smoking or tobacco-use variable. The individuals in all other households were assigned to a second level of this variable. The attached garage variable was considered to be the more important of these two substratification variables. The smoking variable was not used for the Denver stratification due to the smaller stratum sizes.

Another aspect of the third stage sample design was the allocation of individuals to specific days within the sample period. A major purpose of the CO study was to estimate the distribution of personal CO exposures for the study populations during the study season. Of particular interest was the maximum personal CO exposure. Individual CO exposure is heavily dependent upon several factors including: weather, location, and activity patterns. Since weather is such an important factor, it was necessary to field as large a sample as possible on each day during the study period. Otherwise, there could be no one monitored on the days with weather patterns producing the highest CO levels. Since activity patterns are important, the sample participants could not be allowed complete freedom of choice in selecting a day to be monitored. The sample subjects could introduce a bias by selecting mostly days when they plan to be inactive or stay at home. The strong influence of weather and activity patterns upon CO exposure suggests a specific day should be randomly selected for each individal to be monitored. However, it was anticipated that the response rate would be so poor as to invalidate the study if only one day was offered for each sample subject to participate. Hence, the sample for Washington was randomly allocated to non-overlapping three-day interview periods. Likewise, the sample for Denver was allocated to four-day interview periods. Four-day interview periods were used for the Denver sample because each individual selected for Denver was asked to participate for two consecutive days. Each individual in the Washington sample participated for only one day.

The allocation of individuals in the Washington sample to specific three-day interview periods had a greater negative impact on the response rate than had been expected. Some individuals indicated that they were willing to participate, but not within the selected time period. These individuals were given one additional opportunity to participate by randomly reallocating them to one new three-day period. A total of 550 individuals were reallocated in this manner for the Washington sample. Reallocation to new time periods was also allowed for the Denver sample. However, the method of reallocation was somewhat different.

The third stage sample for Washington also incorporated a lead letter methodology study. A sample of 596 individuals was selected to receive a lead letter. A random subsample was selected from each of the strata shown in Table 5.1.6. The lead letter informed the individual that he or she had been selected for monitoring and that a telephone interviewer would be calling soon. The lead letters appear to have had a positive effect upon the response rate. The overall response rate for individuals selected into the Washington sample was about 58 percent, but the response rate for individuals in the lead letter sample was approximately 63 percent. (These response rates are calculated as the number of individuals who agreed to schedule a monitoring appointment divided by the number of individuals selected.) Hence, a person-level response rate of about 65 percent may be possible for future studies of this type. Third stage response and sample weights are also discussed in detail in Whitmore, et al. [1983a].

5.1.5 Third Stage Response

The distribution of final result codes for all individuals selected for CO monitoring in Washington is shown in Table 5.1.7. It is easily seen from the table that appointments were scheduled for about 58 percent of the individuals selected into the sample. However, due to various factors, usable CO monitor data were obtained for only about 36 percent of the individuals sampled. Instrument failure and refusal to carry the monitor were two of the major reasons for the low response rate.

Thus, as shown in Table 5.1.4, approximately 76 percent of the eligible households in the Washington screening sample responded. And, from Table 5.1.7, usable CO monitoring data were obtained for about 36 percent of the individuals selected. These response rates could be improved in the future by sending letters to all individuals selected for monitoring, by reduction of monitor failure, and by making the monitors less intrusive. Like most personal monitoring studies, the CO study achieved a relatively low overall response rate. However, it may be very plausible to presume that the CO exposures of respondents and nonrespondents are alike within weighting classes. If so, the low response rate is not as much of a problem as it might be in some other type of study, e.g., a study of people's attitudes and opinions.

5.1.6 Variance Estimation and Screener Analysis

The sampling design for the CO study is a stratified, three stage design. Area segments defined by 1980 Census block groups are selected at the first stage. Donnelley listings are selected at the second stage. However, the second-stage sample is a multi-phase sample.

Table 5.1.7 Distribution of Final Result Codes for Individuals Selected for CO Monitoring in Washington

Result Code	Interpretation	Frequency N	Frequency %
02	No Contact After Appointment Scheduled	16	0.8
03	Need to be Rescheduled	1	0.1
04	Refused to Keep Appointment	40	2.0
12	Appointment Not Kept - Will Not Reschedule	76	3.8
14	Refused After Field Contact	51	2.6
15	Snowstorm Forced Cancellation	9	0.5
21	Completed Data Collection; Unusable CO Data	132	6.6
22	Partial Data Collected	7	0.4
23	Wrong Person Monitored	2	0.1
24	Monitor Malfunctioned	68	3.4
25	Other Result, Eligible for Monitoring	36	1.8
26	Ineligible (e.g., smoking or illiterate)	11	0.6
30	Usable CO Data	712	35.8
99	Unable to Schedule an Appointment	826	41.6
	TOTAL	1987	100.1

Each sample Donnelley listing is initially assigned to the telephone phase. A subsample of the listings not covered by the telephone phase, e.g., listings with no telephone number, is then selected for a second phase. In particular, the No Previous Contact Sample is a field interview phase of the second stage sample. Moreover, a third phase of the second stage sample is selection of a subsample of listings for the Missed HU Sample. Finally, the third stage sample of people for monitoring is not completely nested within the first-stage sampling units. As a result of these design complexities, exact formulas for estimation of variances and standard errors are complex, if not intractable. Approximate formulas are generally used to obtain appropriate estimates of standard errors with designs of this type. See Whitmore, et al. [1983a] for additional details on this topic. In addition, Whitmore also discusses estimating totals and proportions for the CO screening sample as well as their associated standard errors.

5.2 Survey Activities

This section describes the field survey activities for the project. As described in Section 5.1, survey activities occurred in two phases. Phase I was an initial telephone screen in both Denver, Colorado and Washington, D.C. Phase II involved another telephone interview to identify a specific respondent and to set up an appointment for a field interview. The field interview for the collection of personal exposure monitoring (PEM) data and breath samples followed. RTI performed Phase II in Washington, D.C. only.

5.2.1 Public Relations Efforts in Denver

On August 9, 1982, the survey task leader and other project personnel met in Denver with various city, state, and EPA regional officials. All aspects of the study were discussed. Substantive issues discussed included data requirements, and placement of fixed site monitors in relation to segments selected for personal monitoring. Recommendations were made for placement of additional fixed site monitors. Discussions also centered on the types of local support needed to complete the project and included the need for public relations activities prior to each phase of telephone interviewing.

5.2.2 Data Collection Instrument Development and Approval

Four data collection instruments were developed and reviewed by internal project staff. After revision, they were sent for review by the sponsor. Two of the forms were administered by the Computer Assisted Telephone Interviewing (CATI) system and the sponsor reviewed them for substance only. Those forms were the Household Screening Questionnaire and the Computer Model Input Questionnaire. The remaining forms, the Activity Diary and the Study Questionnaire, were completed directly by the respondents. All forms were finalized and put into the OMB package for approval. (Copies of the forms appear in the Field Interviewer's Manual in Appendix C.)

In early July a draft OMB package was prepared and submitted to EPA for internal review. Based on this review, revisions were made and copies were prepared and sent to EPA on July 27, 1982.

A final version of the OMB package was prepared and submitted on August 18, 1982. (See Appendix D for a Table of Contents of the OMB Package.) The revisions were based on comments supplied by EPA as well as RTI reviews of the earlier draft submissions. The required copies of the form were delivered to the project officer at EPA-RTP. A memo from the EPA project officer denoting interim approval to proceed with the telephone screening phase was received on August 19, 1982. Based on this memo, all activities were continued according to the previously prepared schedule. Formal OMB approval was received later in the month. The OMB number (2080-0003) and expiration date (September 1983) were placed on the data collection instruments.

5.2.3 Phase I - Household Screening Survey

As described above, the first phase of the study was a screening of selected households in Denver and Washington, DC. Information dealing specifically with length of time spent in regular commuting as well as demographics were collected about all members of the household. Specific information collected about the housing unit included presence of gas applicances and presence of an attached garage.

A Computer Assisted Telephone Interviewing (CATI) system was used to perform this task. Local, experienced telephone interviewers were hired and trained and interviewing was begun on August 24, 1982.

5.2.3.1 Computer Assisted Telephone Interviewing (CATI) System

The Computer Assisted Telephone Interviewing system at RTI was used to administer the Household Screening Questionnaire and the Computer Model Input Questionnaire used during Phase II. The CATI system involves programming a computer so that questions are presented on a screen in front of a telephone interviewer. The interviewer enters answers from the respondent directly into the computer data base. The answers entered then interact with the program to select the next question to be presented on the screen and asked of the respondent. In addition, this system provides immediate access to answers for analysis and reduces clerical error introduced in multi-stage data handling operations.

Programming of the Household Questionnaire for the CATI system was started in July 1982. Final testing of the CATI system and the screener were completed a week before the screening phase was implemented. The speed of the machine was somewhat less than desirable, but did not have an effect on the respondents' willingness to participate. After work was completed on the development and testing of the screening questionnaire, initial development of the CATI programming for the Computer Model Input Questionnaire was begun. Testing and refinement was done in an iterative manner. RTI personnel acted as interviewers and respondents during test phases and provided knowledgeable immediate inputs for modifications of the system.

5.2.3.2 Telephone Interviewers

During July 1982, recruiting and hiring of telephone interviewers for the household screening phase was begun by the Telephone Survey Unit. In response to advertisements in local newspapers, over 700 persons requested information about the interviewing positions. All were sent applications and mock interview forms. Those persons whose applications seemed promising were called and asked to administer the mock questionnaire. From those deemed acceptable, the Telephone Survey Unit (TSU) supervisor selected candidates for personal interview and made offers to nineteen persons who accepted positions. All nineteen were trained on Monday, August 23, 1982 and started interviewing after training. One of the nineteen was asked to move into a task leader slot, and two others who were doing unacceptable work could not be successfully retrained and left the project. Replacements were recruited and trained when hired. The Table of Contents of the Telephone Interviewer's Manual is given in Figure 5.2.1.

5.2.3.3 Interviewing

Specifications for the execution of the Computer Assisted Telephone Interview (CATI) data acquisition were provided to the Telephone Survey Unit (TSU) for use during hiring of staff as well as during project operations. A copy is provided in Appendix E.

Interviewing for the Household Screening Questionnaire was implemented in full on Tuesday, August 24th. No major problems occurred and the speed of the interview process increased as the staff gained familiarity with the CATI system and the screener, and as they gained confidence in their ability to use the system.

Telephone interviewing continued through September 21, with the last seven days devoted to conversion attempts of cases which were refusals or breakoffs. Approximately 30% of the recontacted cases were converted to completed interviews. This conversion rate compared favorably with in-person refusal conversions, the method considered most effective. After all conversions were completed, a series of clean-up procedures were applied to the cases. All cases coded as "other" were categorized based on comments in the data file. All cases showing pending codes were reviewed and placed into appropriate final codes. Based on the final cleaned data, a final telephone response rate was calculated by dividing the number of complete screening interviews (6243) by the sum of the completes (6243), the refusals (1142), breakoffs (228), the partial interviews (45), and the number of final others (347) [see Figure 5.2.2]. This final telephone response rate was 78.0%.

Negative publicity in Denver, due to the report of an apparently bogus survey asking highly sensitive questions, led to some problems during the telephone interview. By delaying most of the Denver cases until after a local EPA press conference, most of this negative influence was overcome. In general, the delay in the public announcement of the study presented some obstacles which had to be overcome during the

Figure 5.2.1

TABLE OF CONTENTS OF THE TELEPHONE INTERVIEWER'S MANUAL
(CO Exposure Study)

Page

I. Introduction I-1
    A. Research Triangle Institute I-1
    B. Background and Purpose of the Study I-1
II. Computer Assisted Telephone Interviewing (CATI) II-1
    A. Introduction II-1
    B. CATI Screen II-1
    C. CATI Keyboard II-3
    D. CATI Input II-4
    E. CATI Control Features II-6
    F. Error Messages II-7
III. Administering the Questionniare III-1
    A. Overview III-1
    B. Reaching an Eligible Respondent III-1
    C. Question-By-Question Specifications III-3
IV. Administrative Procedures IV-1
    A. Terms of Employment IV-1
    B. Confidentiality IV-1
    C. Project Interviewing Schedule IV-3
    D. Control Cards IV-3
    E. Scheduling Calls IV-6
    F. Result Codes IV-7
    G. Accounting for Control Cards IV-11

Figure 5.2.2

Final Telephone Interviewing Status Report - Phase I
Screening (Washington, DC and Denver, Colorado)

Listing of Project Codes

FINAL CODES:	NUMBER
01 - Completed Interview	6242
51 - Final Refusal or Breakoff	1142
52 - Refusal or Breakoff, Not Reached for Conversion	228
53 - Circumstantial NI	16
64 - Partial Interview	45
71 - Nonworking Number	1433
72 - Nonresidential Number	278
73 - Entire Household Moving	279
74 - Wrong Address	959
75 - No Reliable Respondent (3 attempts)	57
76 - No Listed Phone Number	1814
81 - Final Phone Problem (confirmed by operator)	15
82 - Final No Answer (6 attempts)	710
83 - Answering Machine (6 attempts)	57
84 - Final Busy (10 attempts)	8
91 and 95 - Other	347

interviews. The use of RTI's toll-free number as a contact point and later the provision of the EPA public affairs number helped allay the fears of the respondents in both Denver and Washington, DC. After the major press releases in the two cities, cooperation and participation were more easily obtained.

5.2.4 Phase II - Washington, DC Area Survey

The second phase of the study developed as two distinct tasks. The first task was an additional round of telephone interviews. The purpose of this round was twofold. The primary reason was to contact a specific member of the household, who was the sample respondent selected, and to further explain the study in an attempt to enroll the selected respondent into the study. Establishing an appointment for a field interviewer to bring the study materials and CO monitor to the respondent was the successful endpoint to this telephone call. The second purpose was to conduct a brief (approximately 25 minute) interview to obtain information about each member (up to the eldest six) of the household. The information sought was for use in one of the extant computer models used to calculate carbon monoxide exposures. This round of telephone interviews was done by RTI for the Washington, DC area sample only.

The second task of Phase II was the actual field sampling. The selected respondents were met at their home or at another convenient location and given all materials. Each respondent carried a personal exposure monitor for the twenty-four hours of their participation. In addition, they carried an Activity Diary to record a description of all their activities and they were asked to complete a self-administered Study Questionnaire by providing information on themselves and their home and work environments. Each time the respondent recorded an activity in the diary, he/she had to push a button on the monitor to record the corresponding CO value for that activity.

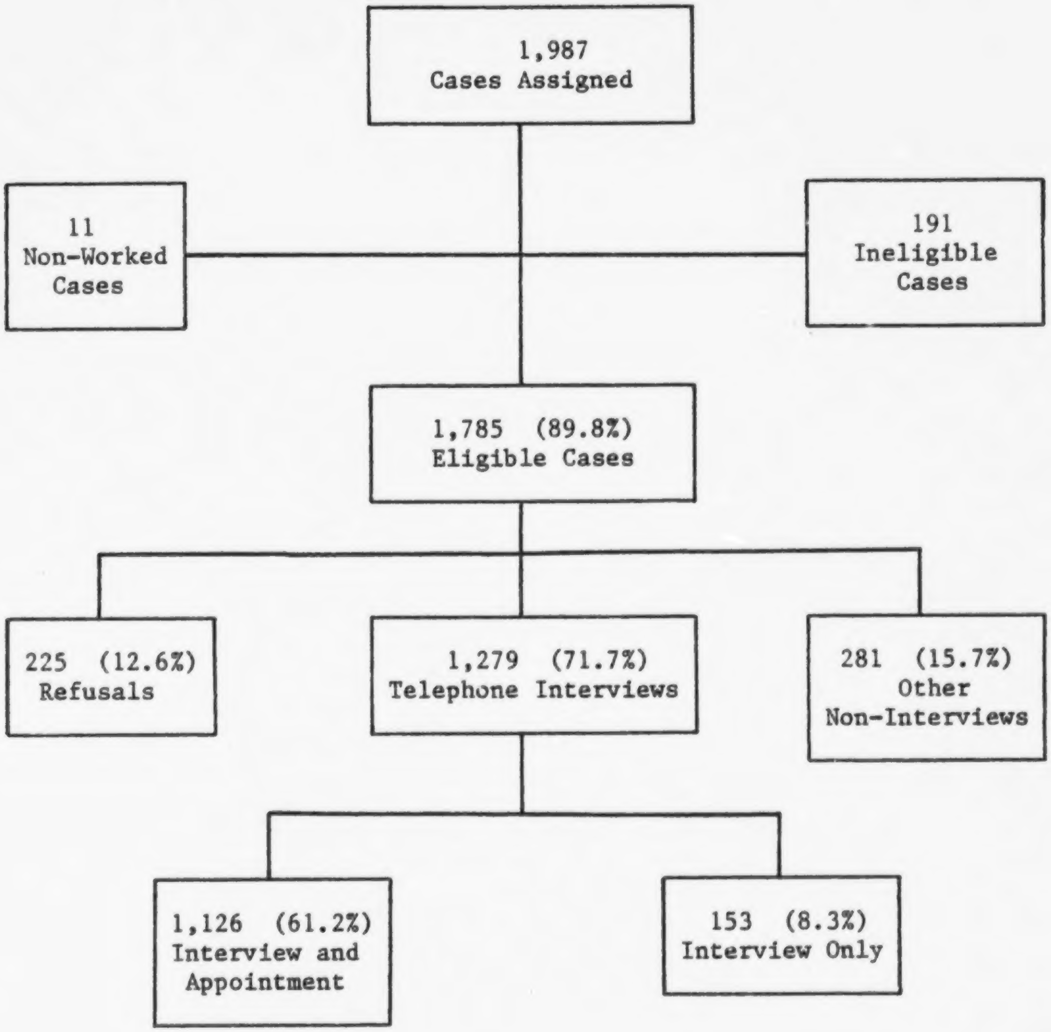
5.2.4.1 Telephone Interviewing

On October 25, a two-hour training session was held at RTI for the telephone interviewing staff who worked on the second phase of the project. The staff consisted for six interviewers and one supervisor, all of whom had worked on Phase I. After training, work on the first wave (15 day sampling period - see Section 5.2.4.8) of interviews of respondents who would participate in the main field study began. Plans were to arrange up to twenty appointments per day, but a delay in the delivery of the monitors caused a reduction to a maximum of ten per day for the first two week period. At the time of this decision, 151 appointments had been made. No further new appointments were made for this time period, but schedules were adjusted in an attempt to yield ten appointments per day. A decision was also made to limit the second wave of interviewing appointments (November 28 through December 12, 1982) to fifteen per day.

Telephone interviewing continued through February with participants from Waves 2 and 3 contacted during November, from Wave 4 contacted during December, from Waves 5 and 6 during January, and from Wave 7 during February.

After the seventh and final wave of telephone interviewing, the following results were obtained. Out of 1987 cases assigned, 1126 had been interviewed by telephone and had scheduled appointments. This is a completion rate of 56.7% (1126/1987). A more accurate response rate can be calculated by removing from the denominator those cases which ended in a status no longer eligible for inclusion in the study. These include those respondents who are physically or mentally incapable (13), those respondents for whom there was a language barrier (20), those cases where the respondent or the entire household had moved (128), and a share of those cases in the 'other' categories (30 cases where a written comment indicates ineligibility). By removing from the denominator these 191 cases and 11 cases not worked because the sampling quotas were completed, the response rate becomes 63.1% (1126/1785). The refusal rate was 225/1785 = 12.6%. When the number of telephone interviews without established appointments is included in the calculations by adding 153 cases to the 1126, a completion rate of 64.4% (1279/1987) and a response rate of 71.7% (1279/1785) are obtained. Figure 5.2.3 displays all of these figures and their relationships. Final rates, which include the field screened cases as well as the telephone screened cases described here, are presented in Section 5.1.5.

Figure 5.2.3 Telephone Response Rates


1,987
Cases Assigned
11
Non-Worked
Cases
191
Ineligible
Cases
1,785 (89.8%)
Eligible Cases
225 (12.6%)
Refusals
1,279 (71.7%)
Telephone Interviews
281 (15.7%)
Other
Non-Interviews
1,126 (61.2%)
Interview and
Appointment
153 (8.3%)
Interview Only

5.2.4.2 Final Document Preparation

During October, all materials for use in the field were prepared, reviewed, and finalized. Copies of all documents were delivered to the EPA project officer and/or to PEDCo for use in Denver. Documents delivered included the second round Telephone Interviewer Manual, a hardcopy version of the Computer Model Input Questionnaire with instructions, the Study Questionnaire, the Activity Diary and instructions, Worksheets and Screeners for the special field activities, and the Field Interviewer Manual. RTI's Duplicating Department reproduced these documents and a Consent/Incentive Receipt Form for use in the field. The Field Interviewer's Manual (Appendix C) contains copies of the forms used in the field. A copy of the Phase II Telephone Interviewer's Manual and the hardcopy version of the questionnaire are given in Appendices B and F.

5.2.4.3 Protection of Human Subjects

A research protocol was submitted to RTI's Committee for the Protection of Human Subjects during October. Permission to proceed was received on October 21, 1982, before fieldwork began. The protocol provides sufficient information for the committee to attest all requirements for the Protection of Human Subjects are being met within the design of the project. The protocol was reviewed by the Coorporate Vice-President. A copy of the protocol submitted and the review letter are attached as Appendix G.

5.2.4.4 Field Staff Recruitment

Potential interviewers were recruited from RTI's National Interviewer File, from recommended interviewers from recent studies conducted in the Washington area, and from responses to newspaper advertisements. A newspaper advertisement for field interviewers for the main field study was run in the Washington Post and local suburban shoppers newspapers. The suburban weeklys generated the most responses. The responses were screened, qualified applicants were called, and appointments for personal interviews in DC were established. Offers were made to those deemed suitable and a staff of fifteen was retained. Based on performance at training and during the early part of the field study, staff adjustments were made. As the project proceeded, the length was extended and additional recruiting took place. This recruiting involved an additional newspaper advertisement and personal recruiting by the current staff. Training was done for new hires by the field supervisor and her assistant.

5.2.4.5 Training the Field Staff

On November 1 and 2, all day training sessions were held in Washington, DC for the field staff which consisted of thirteen interviewers, a field supervisor, and an assistant supervisor. Training covered all aspects of the study including special assignments, regular assignments, problem resolution, and reporting. All staff members left the training with a good grasp of the activities required. Each was given an initial special assignment on Tuesday afternoon (November 2) and was asked to report to the field office on Thursday to have their initial work checked and to receive additional special assignments and their Wave 1 field assignment. With a single exception, no problems were noted after careful review of the first special assignments. All work was done according to specifications. The one exception was an interviewer who had some specific problems and questions. An additional one-half hour of training and some close follow-up of this individual by the supervisor eliminated the problem.

5.2.4.6 Field Office

A field office/laboratory was established in the offices of the Metropolitan DC Council of Governments. One office was allocated for RTI use. The field office served several purposes. It was the supervisor's office and was used to store supplies, maintain records, create assignments, and supervise staff. It served as the location to which all interviewers reported nightly to receive monitors and data collection forms to take to respondents and to which completed materials were returned.

5.2.4.7 Special Field Studies

As described in Section 5.1, three special field studies were undertaken during November to assure complete coverage of the target population. (See Section 5.1 for the rationale for each of these studies.)

5.2.4.7.1 Missed Housing Units

Thirty segments were selected and ten addresses were chosen in each. Each address was located and used as the start of an interval to be checked for missed units. The housing unit to the left of the start point was identified and its address checked against the Donnelley listing for the segment. If it was found on the listing, then the process was complete. If not, the interviewer completed a Household Screening Questionnaire, or obtained a phone number for the housing unit. The interviewer proceeded to the next unit (to the left) and repeated the process. Data from this activity showed a low yield of missed units which is encouraging for future use of the Donnelley lists.

5.2.4.7.2 Segments With No Donnelley Listing

Three segments in the Washington, DC area had no listed housing units on the Donnelley lists. These segments were counted and listed using standard procedures. In two of the segments every house was selected for inclusion, while in the third segment every other house was selected. Members from each selected house were given a chance to complete a Household Screener or to provide a telephone number for later screening from RTI.

5.2.4.7.3 No Previous Telephone Contact

A sample of cases where there was no telephone contact during screening was selected. These cases were worked by the field staff. Respondents were asked to complete a screener or to provide a correct telephone number for interview by phone from RTI.

All three special field studies were completed with information returned to RTI for data entry or subsequent telephone interviewing. During December, the telephone interviewers completed the special field sample activities by entering data obtained in the field or by using the phone numbers obtained to call identified sample units and complete the screening interview. Both processes were done using the CATI system.

5.2.4.8 Regular Field Assignments

CO data were collected in the field in Washington, D.C. from November 8, 1982 through February 25, 1983 with the exceptions of November 24 - 27, 1982 (Thanksgiving weekend), December 22, 1982 through January 3, 1983 (Christmas week), and February 10 - 14, 1983 (heavy snowfall). Cases were assigned to the telephone unit in waves. Original plans called for twenty cases to be assigned to the field per day for each of the fifteen days in a wave. The use of waves of assignments was done in order to keep the time between the telephone contact and the in-person appointment reduced to a workable amount. People are most often reluctant to make definite appointments too far in advance, and if they make the appointment, may forget and make other plans. The use of waves reduced the interval to a maximum of 17 days between telephone call and data collection appointment. The telephone staff was allowed to schedule appointments on any of the three days indicated for each case (see Section 5.1), thus allowing some flexibility for the respondent. After all cases in a wave were worked, those cases with scheduled appointments were sent to the field. The field supervisor divided the control cards into assignments for the interviewers. Assignments were created with an attempt to minimize driving time. Each field interviewer was required to make a reminder telephone call to the respondent at least twenty-four hours before the appointment. This call reconfirmed the appointment and was used to get specific directions to the house.

Prior to the appointment, the interviewer reported to the central office and was issued a monitor and all required data collection forms. The interviewer went to the respondent's home, further explained the study, obtained informed consent, and made an appointment to return in twenty-four hours to retrieve all materials and to pay the incentive.

Cases were first assigned to the interviewing field staff on November 4. This allowed sufficient time for the required reminder calls to be made before the initial PEM delivery appointments which started on November 8. In general, no major problems were encountered in the field. However, the amount of driving involved in getting to and from the respondents' homes created a logistics problem as did creating an interviewer's work assignment which permitted time off. The addition of staff reduced these problems. Problems with the monitors created some lost data situations, but, by the end of November, this was being reduced. There were some problems with rescheduling broken appointments. An immediate attempt was made to reschedule within the three-day sampling period. When unsuccessful, the case was returned to RTI for rescheduling in a different wave. This process enabled RTI to maintain a high rate of participation. All activities ran until December 22 when work was stopped for a holiday break. Other than one day of field activity lost due to inclement weather (heavy snowfall), all activities proceeded as planned.

The field response rate was somewhat lower than planned during January. This was attributed to continued monitor failures and to a somewhat higher than expected refusal rate. Broken appointments or requested reschedules also decreased the completion rate.

Three snow days in Washington delayed field sampling during early February. The delay caused the rescheduling of the three days' appointments to three days appended at the end of the scheduled wave. The rescheduling of appointments was handled by the field interviewers, since all RTI telephone operations had been terminated. During February, the newly developed monitoring package, involving the Hewlett-Packard calculator and interface was made available. From the units available, equipment problems reduced the number of opportunities to place the monitor with respondents, and minimal data were collected. Most respondents liked the new device, and, in several instances, a different member of the household had carried the original PEM, allowing for good comparative data. The problems reported by the respondents included the size of the keys (too small to push easily) and the size of the lettering of the labels, also too small.

All data and forms were received from the field by the end of February and batched and logged in according to instructions prepared for this phase of the study. Counts of each document were used to account for all cases and were used to determine final response and refusal rates.

5.2.4.9 Breath Sampling

Each respondent was asked to provide a breath sample at the end of the 24-hour monitoring period. Following a standard protocol, which the interviewer read to the respondent, the respondent was asked to take a deep breath and hold it, and then expel it fully. Another deep breath was taken and held. After half of the second breath was expelled, the remaining volume was collected in the sample bag through a disposable mouthpiece. The sample bag was sealed, labelled with the respondents unique study number, and returned to the lab for analysis. After analysis was completed, the bags were recycled into the system. The repetative use caused some problems due to leakage of sampling bags and loss of samples (i.e., some bags sent back to the field developed leaks after being used several times). This loss of samples was the only major field problem encountered. There appeared to be no major difficulty involved with the actual collection of the samples.

At the request of EPA, RTI also collected breath samples from children ages 5-7 in households of respondents. Breath sampling of children started slowly as few children in the age range of 5-7 years were found. Field staff were instructed to expand the age range to 4-8 during December. The acceptable age range was further expanded during January.

Acquisition of breath samples from children continued slowly. Even with the increased age range and increased interviewer awareness and diligence, only 12 samples were collected.

5.3 Field Measurements and Quality Assurance

The field measurement of personal exposure levels of carbon monoxide was accomplished using battery-powered, portable CO monitors. Two configurations of the CO monitor were evaluated in Washington, DC. However, virtually all of the ambient data were acquired from one configuration. The use of such monitors required extensive, daily technical support on-site to keep the monitors functioning properly. This support was provided from an on-site, field laboratory staffed with two full-time technicians working seven days per week throughout the study.

5.3.1 Description of the Ambient Monitors

The monitoring of ambient levels of CO was accomplished using two configurations of portable, battery-operated monitors which were assembled from commercially-available subassemblies by Rockwell

International for EPA. Each of the monitor configurations was composed of two major subsections -- the CO monitoring subsection and the data acquisition subsection. In each configuration, the CO monitoring subsection consisted of a specially modified General Electric CO-3 carbon monoxide monitor. This monitor operated on the principle of a reversed fuel cell. A small, diaphragm pump within the monitoring subsection drew a sample of ambient air into the monitor through a prefilter designed to remove reducing species (e.g., alcohols, aldehydes, ketones, etc.) within the sample. The sample was then passed through the detector cell where it came into contact with a moist, polymeric membrane containing a wiring grid which conducted a small, constant electric current. In the presence of the electrical current, the CO in the sample reacted with the water in the membrane to form CO_2 and H_2. This reaction resulted in a slight alteration in the grid current. The current alteration was sensed by the monitor's electronics which transformed the signal into an analog output voltage proportional to the CO concentration in the sample. The electronics package within the monitor contained provisions for adjusting the zero- and span-level responses as well as for electrically adjusting flow rate by controlling pump speed.

The two monitor configurations differed in their data acquisition subassemblies. One configuration, the model COED-1, utilized a data acquisition package supplied by Magus, Inc. The second configuration, the so-called GE/HP model, utilized a Hewlett-Packard HP-41CV programmable calculator and a HP-IL interface loop and converter as the data acquisition unit. In both configurations, the continuous analog voltage from the GE monitoring unit was fed into the data unit where it was formatted into time-period averages which were stored in on-board memory for later manual acquisition. The definition of the time-period averages was accomplished either by an on-board clock (i.e, time periods which were hourly averages) or by user-initiated "activity signals" (i.e., averages based on periods of specific activities). The output from the Magus data unit consisted of time/average pairs where the average datum represented the true arithmetic average of the CO concentration for a time period and the time datum represented the actual time, in 24-hour clock, that the pair was stored (i.e., the time that the time or activity period was completed). The scanning rate for this data unit was about 6 per minute. The average was computed by accumulating the sum of the individual scan values obtained during an individual time period and dividing it by the number of scans within the period at the end of the period. The Magus unit was capable of storing about 120 time/average pairs, but was capable of defining only one type of activity. The program operating the Magus was primarily "hard wired" (i.e., unaccessible to the user), although some limited operating parameters were user-selectable.

The HP data unit also output time/average pairs, but was capable of being programmed to retain in memory (and, subsequently output) additional data with each pair. Examples of such additional data included the minimum and maximum scan value within a time period, the standard deviation of period data, the number of observations (i.e, scans) within a period, etc. Since the HP system was based on a continuous-memory, fully-programmable, scientific function calculator, any statistic desired could be computed and retained for each time period subject only to the time constraints of the data acquisition cycle and the available memory of the calculator. The memory of the unit, as configured for this project, approached 4,800 bytes thereby allowing the user a fair amount of flexibility concerning what data and how much data was acquired during a sample. The HP units were programmed for this project to differentiate between ten different activity designations. The activity designation was stored with the time/average pair. The scanning rate was programmed at 4 per minute. The unit output data to a small-format, thermal printer, but could be configured to off-load stored data to magnetic tape or to a mini-computer.

5.3.2 Description and Verification of the Field Standards

The field standards used for calibrating the CO monitors were generated from multiple cylinder gases at pre-selected concentration levels rather than from dynamic dilution of a single, high concentration standard. This alternative was chosen to minimize the time required for standard preparation in the field. An additional benefit derived from the use of fixed concentration standards was the elimination of the day-to-day variation in standard concentration levels. Cylinders of carbon monoxide in air were obtained from Airco Industrial Gases, RTP, NC at concentration levels of 10, 50, 100, 150, and 200 ppm (v/v). A certificate of analysis was required with each cylinder ordered. Additionally, prior to use in the field, each cylinder was verified in the RTI Environmental Standards Laboratory against NBS SRM or CRM standards or against RTI GMPS (Gas Manufacturer's Primary Standard) cylinders.

Since the Airco standards were composed of a synthetic air matrix (i.e., pure oxygen and pure nitrogen blended to approximate the composition of air), the oxygen content of each cylinder ordered was verified to be 20.8 ± 0.5 percent. Since EPA ruggedness testing of the monitors prior to the project had revealed no carbon dioxide or water vapor interference, these gases were omitted from the standard gas matrices.

Airco 0.1 Grade Zero Air was utilized as the zero-level matrix. This gas also was dry and contained no CO_2. It was certified by Airco as containing less than 0.1 ppm CO and was verified at RTI at the same level.

5.3.3 Preparation of CO Monitors for the Acquisition of a CO Exposure Sample

The following procedure was performed on a daily basis on every monitor assigned to a project sample. In the early afternoon, prior to delivery to the field interviewers, the sampler was provided with fresh batteries (if its batteries had not been charged overnight the previous night), powered-on, and allowed to operate on a maintenance charger for approximately 1 hour. During this warm-up period, the monitor's clock was set (if necessary), the user-selectable program options were set, and the pre-scrubber and cell water reservoir were checked and serviced, if necessary. The pre-scrubber was replaced or refilled with 1/16" Purafil® (potassium permanganate coated on silica) spheres when its normal pink color had changed to brown halfway down the column. The water reservoir was refilled with deionized water whenever it was found less than half full.

Following the warm-up period, the monitor was moved to the calibration manifold and, again, connected to a maintenance charger. Monitor flow rate was measured and adjusted to 70 ± 10 sccm, if necessary. If this flow specification could not be met, the monitor was removed from service until the problem could be diagnosed and corrected. The monitor was subjected to a two-point, zero/span check at CO concentration levels of 0.0 and approximately 50 ppm. The two-point check was deemed adequate due to the high degree of linearity ($0.9993 \leq r^2 \leq 0.9999$) demonstrated by pre-study, post-study, and within study multipoint calibrations covering a 0 - 200 ppm range. Zero and span responses were monitored both at the analog voltage output from the GE monitoring section and at the digitized and integrated (5 minute integration periods) output from the data unit. The zero response of the monitor was adjusted to a nominal level of 1.0 ppm whenever response to the zero concentration matrix fell outside of the 0.5 to 2.5 ppm range as determined at the GE monitor analog output. A nominal zero setting of 1.0 ppm, rather than 0.0 ppm, was chosen to avoid the likelihood of negative responses to near-zero concentration levels due to monitor drift. This was necessary because the Magus data unit interpreted all incoming negative data as the absolute of the data, thus leading to possibly large errors in accumulated averages. The span response was adjusted whenever the response to the span matrix varied by more than ± 5 percent from the nominal value as determined at the GE monitor analog voltage output. After all adjustments were completed, the responses to the zero and span matrices were redetermined and the slope and intercept of the response curve were computed based on the 5 minute integrated data output from the data unit.

Following the zero/span operation, the monitor was removed from the maintenance charger and allowed to operate for 5-10 minutes. During this time the sample operating parameters were established (e.g., memory clear, auto-log mode on, time-display mode selected, and data logging enabled). After 5-10 minutes had elapsed, the battery voltage for each of the battery packs was measured at the pack. The GE CO monitor battery voltage was expected to be 5.65 ± 0.10 volts, the Magus voltage was to be 8.40 ± 0.10 volts, and the GE/HP voltage was to be 5.2 - 6.4 volts. If these voltage specifications were not met, the battery pack was replaced with a freshly charged one. If the specification was still not met, the monitor was removed from active status until the problem was diagnosed and corrected. Following the battery check, the monitor cover was installed and secured and the monitor was stored (with the sample pump running) on a maintenance charger until delivery to the field interviewer (FI). The monitor was delivered to the FI within 0-2 hours of calibration, generally.

Following the sample period, the monitor cover was removed, the monitor was inspected for obvious problems (e.g., dead batteries, depleted prescrubber, physical damage, etc.), the sample pump was turned off, and the data unit was placed in the "display" mode for data recovery. The data were transcribed from monitor memory to the field data sheet by the field interviewer. Ten percent of the incoming monitors on any given day were subjected to a QC data reread where the monitor-to-data-sheet transcription was checked point-by-point. Discrepancies were resolved immediately and the FI was notified of the findings and resolutions.

The battery voltage(s), the water reservoir level, and the prescrubber condition were, again, checked and noted. The zero/span check was repeated, however, no adjustments were made. This post-sample check was performed with the monitor operating on its internal batteries only and not connected to a maintenance charger. Again, the slope and intercept of the response curve were computed based on integrated output from the data unit. The post-sample response curve was compared with the pre-sample curve and an appropriate data validity code was assigned to the sample. All computations connected with the pre- and post-sample zero/span operations including calculation of percent variation, slope, and intercept and assignment of validity code were performed by a Hewlett-Packard Model 41-C programmable calculator operating under the control of a program prepared by RTI field personnel especially for this project.

The following specifications defined the range of each validity code:

Code	Slope	Intercept
1	$\lvert \Delta M \rvert < 5\%$	$\lvert \Delta b \rvert < 1.0$ ppm
2	$5\% \leq \lvert \Delta M \rvert < 10\%$	$1.0 \text{ ppm} \leq \lvert \Delta b \rvert < 1.5$ ppm
3	$10\% \leq \lvert \Delta M \rvert < 15\%$	$1.5 \text{ ppm} \leq \lvert \Delta b \rvert < 2.0$ ppm
4	$\lvert \Delta M \rvert \geq 15\%$	$\lvert \Delta b \rvert \geq 2.0$ ppm

where:

$$\Delta M = \frac{M_2 - M_1}{M_1} \times 100$$

$$\Delta b = b_2 - b_1 ,$$

and:

M_2 = post-sample slope,
M_1 = pre-sample slope,
b_2 = post-sample intercept, and
b_1 = pre-sample intercept.

Whenever the codes for the slope and intercept differed, the most conservative one (i.e., the code of higher number) was chosen.

The computation of applicable slope and intercept for ambient data reduction was based on the validity code assigned to the data. If the assigned code was 1, then the applicable slope and intercept were equal to the pre-sample zero/span slope and intercept. If the assigned code was 2, 3, or 4, then the applicable slope and intercept were the averages of the pre- and post-sample slopes and intercepts, respectively.

Monitors which failed to complete a post-sample zero/span check were assigned a validity code of 5 and all ambient data from the sample were flagged as invalid. This situation usually occurred because of insufficient battery capacity, but may also have been caused by data unit malfunctions such as "lock-up" or "mode shift".

All data derived during zero/span operations were recorded on a "Monitor Status Sheet" such as those depicted in Figures 5.3.1 and 5.3.2. Ambient data recovered from monitor memory were transcribed onto the "Field Data Sheet" depicted in Figures 5.3.3 and 5.3.4. Zero/span data were also transferred to control charts describing the course of

CO EXPOSURE STUDY, WASHINGTON, DC
MONITOR STATUS SHEET

MONITOR EPA NO. ________ SHEET NO. ________ COND. CODE ________

PID # ______________
Sample Date ______________

CO STD ID ________
CO STD Conc ________

PARAMETER	NOMINAL RANGE	PRE-SAMPLE VALUE	POST-SAMPLE VALUE	
Date	---			
Time	---			
Analyst	---			
Barometric Pressure	750-770 mm			
Laboratory Temp.	20-30°C			
Zero Response (Unadj)	0 ± 2 ppm			
Span Response (Unadj)	~50 ppm			
Span Variation (Unadj)	± 5%			
Zero Response (Adj)	0 ± 2 ppm		xxxxx	
Span Response (Adj)	~50 ppm		xxxxx	
Span Variation (Adj)	± 5%		xxxxx	
Integrator Zero Resp.	0 ± 2 ppm			
Integrator Span Resp.	~50 ppm			
Zero Intercept	0 ± 2 ppm			
Slope	1.00 ± 0.05			
Flow Rate (Unadj)	70 ± 10 sccm			
Flow Rate (Adj)	70 ± 10 sccm		xxxxx	
Battery Voltage				
CO-3 Unit	5.65 ± 0.05 volts			4.95 ± 0.05v
Integrator	8.40 ± 0.05 volts			7.75 ± 0.05v
Water Level	1/2-3/4 Full			
Pre-Scrubber level	1/2-1/1 Pink			

COMMENTS: ______________________________

Figure 5.3.1. COED-1 Monitor Status Sheet

CO EXPOSURE STUDY, WASHINGTON, DC
GE/HP MONITOR STATUS SHEET

MONITOR EPA NO. ________ SHEET NO. ________ COND. CODE ________

PID # ________________ CO STD ID ________
Sample Date ____________ CO STD Conc ________

PARAMETER	NOMINAL RANGE	PRE-SAMPLE VALUE	POST-SAMPLE VALUE
Date	---		
Analyst	---		
Barometric Pressure	750-770 mm		
Laboratory Temp.	20-30°C		
Zero Response (Unadj)	0 ± 2 ppm		
Span Response (Unadj)	50 ppm		
Span Variation (Unadj)	± 5%		
Zero Response (Adj)	0 ± 2 ppm		xxxxx
Span Response (Adj)	50 ppm		xxxxx
Span Variation (Adj)	± 5%		xxxxx
Integrator Zero Resp.	0 ± 2 ppm		
Integrator Span Resp.	50 ppm		
Zero Intercept	0 ± 2 ppm		
Slope	1.00 ± 0.05		
Flow Rate (Unadj)	70 ± 10 sccm		
Flow Rate (Adj)	70 ± 10 sccm		xxxxx
Voltages			
Pump	---		
Batteries	6.4 to 5.2 volts		
Cell Temperature	20 to 30 deg		
Water Level	1/2-3/4 Full		
Pre-Scrubber level	1/2-1/1 Pink		

COMMENTS: ____

Figure 5.3.2. GE/HP Monitor Status Sheet

CO EXPOSURE STUDY, WASHINGTON, DC
FIELD DATA SHEET

Monitor ID: ☐☐☐☐☐☐

Status Sheet No. ☐☐☐

PID #: ______________________

Read by: ☐☐☐☐☐☐

Verified by: ☐☐☐☐☐☐

Approved by: ☐☐☐☐☐☐

	Month	Day	Year
Date Sampled:	☐☐	☐☐	☐☐
Date Read:	☐☐	☐☐	☐☐
Date Verified:	☐☐	☐☐	☐☐
Date Approved:	☐☐	☐☐	☐☐

NOTE: 1 - Use back of form to describe any problems.
2 - Record all times in 24-hr clock.

Seq. No.	Time	Value (ppm)	Seq. No.	Time	Value (ppm)
01	☐☐☐☐	☐☐☐.☐	25	☐☐☐☐	☐☐☐.☐
02	☐☐☐☐	☐☐☐.☐	26	☐☐☐☐	☐☐☐.☐
03	☐☐☐☐	☐☐☐.☐	27	☐☐☐☐	☐☐☐.☐
04	☐☐☐☐	☐☐☐.☐	28	☐☐☐☐	☐☐☐.☐
05	☐☐☐☐	☐☐☐.☐	29	☐☐☐☐	☐☐☐.☐
06	☐☐☐☐	☐☐☐.☐	30	☐☐☐☐	☐☐☐.☐
07	☐☐☐☐	☐☐☐.☐	31	☐☐☐☐	☐☐☐.☐
08	☐☐☐☐	☐☐☐.☐	32	☐☐☐☐	☐☐☐.☐
09	☐☐☐☐	☐☐☐.☐	33	☐☐☐☐	☐☐☐.☐
10	☐☐☐☐	☐☐☐.☐	34	☐☐☐☐	☐☐☐.☐
11	☐☐☐☐	☐☐☐.☐	35	☐☐☐☐	☐☐☐.☐
12	☐☐☐☐	☐☐☐.☐	36	☐☐☐☐	☐☐☐.☐
13	☐☐☐☐	☐☐☐.☐	37	☐☐☐☐	☐☐☐.☐
14	☐☐☐☐	☐☐☐.☐	38	☐☐☐☐	☐☐☐.☐
15	☐☐☐☐	☐☐☐.☐	39	☐☐☐☐	☐☐☐.☐
16	☐☐☐☐	☐☐☐.☐	40	☐☐☐☐	☐☐☐.☐
17	☐☐☐☐	☐☐☐.☐	41	☐☐☐☐	☐☐☐.☐
18	☐☐☐☐	☐☐☐.☐	42	☐☐☐☐	☐☐☐.☐
19	☐☐☐☐	☐☐☐.☐	43	☐☐☐☐	☐☐☐.☐
20	☐☐☐☐	☐☐☐.☐	44	☐☐☐☐	☐☐☐.☐
21	☐☐☐☐	☐☐☐.☐	45	☐☐☐☐	☐☐☐.☐
22	☐☐☐☐	☐☐☐.☐	46	☐☐☐☐	☐☐☐.☐
23	☐☐☐☐	☐☐☐.☐	47	☐☐☐☐	☐☐☐.☐
24	☐☐☐☐	☐☐☐.☐	48	☐☐☐☐	☐☐☐.☐

If data continued on back of page, check here ☐

Data Validity Code: ☐

Applicable Slope: ☐.☐☐☐

Applicable Intercept: ☐.☐☐☐

Figure 5.3.3. Field Data Sheet, Side 1

PID #: ______________________________ Page 2

Seq. No.	Time	Value (ppm)	Seq. No.	Time	Value (ppm)
49		.	73		.
50		.	74		.
51		.	75		.
52		.	76		.
53		.	77		.
54		.	78		.
55		.	79		.
56		.	80		.
57		.	81		.
58		.	82		.
59		.	83		.
60		.	84		.
61		.	85		.
62		.	86		.
63		.	87		.
64		.	88		.
65		.	89		.
66		.	90		.
67		.	91		.
68		.	92		.
69		.	93		.
70		.	94		.
71		.	95		.
72		.	96		.

Comments: ____

Figure 5.3.4. Field Data Sheet, Side 2

differences between pre-sample and post-sample span, zero, battery voltage, and flow rate values. Examples of these charts are presented and discussed in Section 6.3.3.5 of this report. Complete files of the data sheets and control charts, organized on a monitor-by-monitor basis, will be transferred to EPA at the conclusion of the project.

5.3.4 Analysis Method for Carbon Monoxide in Breath

A study was undertaken to develop and evaluate a method for collecting and measuring alveolar carbon monoxide prior to the field study. The effects of sampling bag, sample storage, measurement time, and instrument interferences on measured CO were investigated using a single General Electric CO-3 monitor identical to the ones used for breath analysis in the field. Calibration curves were generated under several conditions to assess both precision and accuracy of the measurement method. Finally, the precision of the final method was tested by collecting and measuring four breath samples from each of eight nonsmoking subjects. Since EPA loaned RTI only one CO-3 monitor and the field study started within two weeks after the instrument was received, a very limited amount of time was available to conduct these experiments. Accordingly, the number of determinations for each experiment were not statistically designed. This led to an unequal number of determinations in the various experiments.

5.3.4.1 Description of Method

Alveolar CO was measured using a General Electric CO-3 monitor equipped with an on-line activated charcoal/Purafil® prefilter to remove potential interferences from breath samples. The filter was prepared by filling a 10 mL disposable pipette with 9.0 cm of Purafil® (potassium permanganate coated silica spheres) and 9.5 cm activated cocoanut charcoal. The Purafil® consisted of 1/16" spheres and the charcoal was 6-14 mesh. The filter was attached to the sample inlet of the CO monitor at the end containing Purafil®. A strip chart recorder was attached to the monitor for output signal recording.

The following technique was used to acquire a field sample. The participant was instructed to take a deep breath then expel all air from his lungs. He took a second deep breath and held this breath for 20 seconds. He then expelled the first part of his breath into the room and the last portion into a sample bag. The bag was sealed by clamping the inlet tube and was transported back to the field laboratory for breath analysis. For analysis, the bag was attached to the GE monitor with the prefilter in line and the measurement was taken after the strip chart trace had stabilized. The amount of CO in the sample was determined from the recorder trace by transforming it to a concentration value according to the monitor's calibration curve.

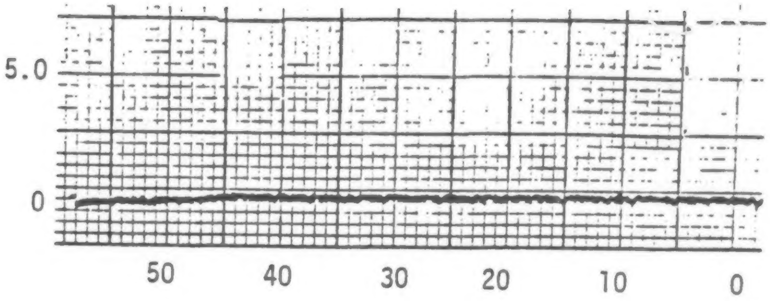
5.3.4.2 Instrument Noise

The General Electric CO-3 monitor was tested for output signal noise while monitoring zero gas (0.0 ppm CO) from a gas mixing manifold. Instrumental noise was characterized as one half the peak to peak variation in the signal output. Figure 5.3.5 shows the recorder tracing obtained during testing. Noise was determined to be at ± 0.2 ppm for this instrument.

5.3.4.3 Instrumental Response Time

Instrumental response time was determined for the GE CO-3 monitor using CO concentrations ranging from 5 to 50 ppm. The strip chart recorder was used to monitor instrument output over time. Measurements were made with the monitor attached directly to the CO source with and without the charcoal/Purafil® prefilter in-line. Under both conditions, gas flow through the monitor was adjusted to 75 mL/min.

The monitor response was considered stable once the recorder had maintained the same reading for at least 30 seconds. Stabilization times for all conditions are listed in Table 5.3.1. Stabilization times varied from 1.5 to 7.5 minutes with the longest times required for the highest CO concentrations. In addition, the times required for the monitor to reach 90 and 95 percent of the final stabilized reading were measured and have been listed in Table 5.3.1. These times were also dependent on concentrations, but in all cases, values were less than 2.5 minutes. The increased stabilization time for those samples employing the in-line filter was due to the air volume contained within the filter. These data demonstrated that for the CO concentrations expected in nonsmoking subjects (10 ppm or less), the instrument with the prefilter in-line will reach 95 percent of the actual CO concentration in less than 2 minutes and will reach stabilization after 4.5 minutes. At



Time (minutes)

Figure 5.3.5 Instrument Noise

Table 5.3.1 Instrument Response Times in Minutes

CO Concentration (ppm)	Percent Stabilization		
	90% 1/	95% 2/	100% 3/
5.0	0.3	0.4	1.5
5.0 4/	1.0	1.4	2.8
8.0	0.5	0.7	4.0
8.0 4/	1.4	1.7	4.5
10.0	0.4	0.5	1.5
10.0 4/	0.6	0.8	2.0
31.0	0.5	0.9	4.5
31.0 4/	1.3	1.7	6.5
50.0	0.7	1.7	5.5
50.0 4/	1.6	2.3	7.5

1/ Time at which the instrument reached 90% of the final stabilized reading.

2/ Time at which the instrument reached 95% of the final stabilized reading.

3/ Measured after instrument had given a stable reading for 30 seconds.

4/ Measured with prefilter on-line.

an air flow of 75 mL/min, these times correspond to a sample volume of 150 and 420 mL, respectively. This information verified that a 600 mL sample bag could provide an adequate sample volume for accurate readings.

As well as determining the stabilization time for the monitor to respond to the presence of CO, the time required for the monitor to reequilibrate at a zero level after exposure to CO was studied. It was determined the the GE monitor would equilibrate at zero within two minutes after exposure to CO levels as high as 15 ppm.

5.3.4.4 Sample Bags - Recovery Study

Experiments were performed to determine the amounts of CO lost from spiked air loaded into two types of sampling bags: 600 mL blood transfer bags (Fenwal, Inc.) and 1 L carboxyhemoglobin bags (Energetics Science Division, Becton-Dickenson). During testing, CO concentrations were first measured by attaching the CO monitor directly to the gas mixing manifold. Finally, CO concentrations in the bag air were measured immediately after filling the bags. Experiments were performed using CO concentrations ranging from 2.5 to 15.5 ppm with both dry and humid air (75% relative humidity). A new sampling bag was used for each measurement. A single measurement was performed for each condition. Results are given in Tables 5.3.2 and 5.3.3. The data show that a reproducible loss of CO occurred for each bag regardless of CO concentration. The Fenwal bags showed an average loss of 1.7 ± 0.5 ppm CO while the carboxyhemoglobin (CBH) bags showed a loss of only 0.3 ± 0.2 ppm CO.

With both bags, there appeared to be greater CO losses when dry, rather than humid, air was used. Due to high CO losses, the Fenwal bags were considered unacceptable. All further testing was performed using only the carboxyhemoglobin bags.

5.3.4.5 Sample Contamination from CBH Bags

Contamination of samples resulting from their storage in the CBH bags was examined. Humidified zero air was placed into three bags and analyzed immediately. Next, humidified zero air was placed into three bags and stored for approximately 20 hours. No elevation of the zero CO response level was observed for either set of samples.

Table 5.3.2 Loss of CO From Fenwal Sampling Bags

Air Type	Measured [CO] (ppm) Manifold	Bags	CO Lost
humid	15.5	13.8	1.7
dry	15.5	12.8	2.7
humid	12.3	10.3	2.0
humid	8.8	7.8	1.0
dry	8.8	7.0	1.8
dry	8.0	5.8	2.2
humid	5.8	4.3	1.5
dry	5.8	3.8	2.0
dry	2.8	1.4	1.4
humid	2.5	1.3	1.2
dry	2.5	.8	1.7
	Average Humid ± S.D.		1.5 ± 0.4
	Average Dry ± S.D.		2.0 ± 0.5
	Average Both ± S.D.		1.7 ± 0.5

Table 5.3.3 Loss of CO From CHB Sampling Bags

Air Type	Measured [CO] (ppm) Manifold	Bags	CO Lost
humid	7.0	6.8	0.2
dry	7.0	6.8	0.2
humid	3.0	2.8	0.2
dry	3.0	2.4	0.6
dry	2.8	2.4	0.4
	Average Humid ± S.D.		0.2 ± 0.0
	Average Dry ± S.D.		0.4 ± 0.2
	Average Both ± S.D.		0.3 ± 0.2

5.3.4.6 Effect of Various Parameters on Breath CO Measurement

Air spiked with CO at known concentrations was measured under several conditions. Measurements were taken with the monitor attached directly to the CO source, to the CO source with the prefilter in-line using both dry and humid air, and to the bag with the prefilter in-line using humid air spiked with ethanol at a concentration of 5 ug/L. Measurements from the CHB bags were made with and without storage.

Table 5.3.4 shows measured CO concentrations with the monitor attached directly to the gas mixing manifold with and without the prefilter on-line. Table 5.3.5 shows measured CO concentrations with the monitor attached to the gas mixing manifold with the prefilter in-line using dry and humid air. A single measurement was made for each condition. The instrument was allowed to rezero using ambient air after each measurement. Results show no significant differences in measured CO under the conditions tested.

Tables 5.3.6 through 5.3.8 show comparisons of spiked air sampled directly from the gas mixing manifold to measurements for air taken from the same source, but loaded into CHB sampling bags prior to measurement. Experiments were performed at three CO concentrations (3, 7, and 15 ppm). The prefilter was in-line for all measurements. Bags were first flushed and then filled with air to minimize carry-over effects. Results show some loss from sampling bags. Losses appear to be greatest for dry air with a storage period, but the data are not conclusive. During storage, a mean loss of 0.8 ± 0.4 ppm was observed for dry air samples over all tested concentrations. Samples using humid air showed a loss of 0.6 ± 0.3 ppm CO from the bags.

Data in Table 5.3.9 show measured CO values for air spiked with ethanol sampled under a variety of conditions. All measurements were taken with the prefilter on-line. Ethanol does not appear to affect the CO measurement. The general trend of some sample loss from the bag over time appears to have also occurred during this experiment.

Table 5.3.4 Effect of Filter on Measured CO

CO Source	Air Type	Measured [CO] (ppm)		
manifold - no filter	dry	5.0	8.0	31.5
manifold - filter on-line	dry	5.0	8.0	31.5

Table 5.3.5 Effect of Humid Air on Measured CO

CO Source	Air Type	Measured [CO] (ppm)		
manifold - filter	dry	2.8	7.0	15.5
manifold - filter	humid	3.0	7.0	15.5

Table 5.3.6 Effect of Storage in Sampling Bags on CO Measurement at 3 ppm CO

CO Source 1/	Air Type	Storage Time (h)	Measured [CO] (ppm)
manifold	dry	0	2.9 ± 0.1 2/
manifold	humid	0	3.0 3/
CHB bag	dry	0	2.4 ± 0.2 4/
CHB bag	humid	0	2.8 3/
CHB bag	dry	18	2.5 ± 0.3 2/
CHB bag	humid	18	2.7 ± 0.1 2/

1/ Measured with filter on-line.
2/ Triplicate determinations ± S.D.
3/ Single determination.
4/ Duplicate determination ± mean deviation.

Table 5.3.7 Effect of Storage in Sampling Bags on CO Measurements at 7 ppm CO

CO Source 1/	Air Type	Storage Time (h)	Measured [CO] (ppm)
manifold	dry	0	7.0 2/
manifold	humid	0	7.0 2/
CHB bag	dry	0	6.8 2/
CHB bag	humid	0	6.8 2/
CHB bag	dry	23	6.3 ± 0.3 3/
CHB bag	humid	23	6.3 ± 0.3 3/

1/ Measured with filter on-line.
2/ Single determination.
3/ Triplicate determinations ± S.D.

Table 5.3.8 Effect of Storage in Sampling Bags on CO Measurements at 15 ppm CO

CO Source 1/	Air Type	Storage Time (h)	Measured [CO] (ppm)
manifold	dry	0	14.8 2/
manifold	humid	0	14.8 2/
CHB bag	dry	20	13.1 ± 0.5 3/
CHB bag	humid	20	13.9 ± 0.1 3/

1/ Measured with filter on-line.
2/ Single determination.
3/ Triplicate determinations ± S.D.

Table 5.3.9 The Effect of Ethanol on Measured CO

CO Source 1/	Air Type	Storage Time (h)	Measured [CO] (ppm)
manifold	humid	0	15.5 2/
CHB bag	humid	0	15.2 ± 0.1 1/
manifold	humid	0	7.3 2/
CHB bag	humid	0	6.8 ± 0.0 1/
manifold	humid	0	3.3 2/
CHB bag	humid	0	3.1 ± 0.3 1/
CHB bag	humid	18	2.7 ± 0.1 1/
manifold	humid	0	-0.3 2/
CHB bag	humid	0	-0.3 ± 0.0 1/

1/ Triplicate determinations ± S.D.
2/ Single determination.

5.3.4.7 Interference Due to Plastic Mouthpiece

Interferences or losses of CO due to the use of a disposable mouthpiece were determined. No noticeable CO interferences were observed when using the mouthpieces. An average loss of 0.7 ± 0.2 ppm CO occurred when using humid air spiked with 6.3 ppm CO loaded into and measured from a CHB sampling bag with the mouthpiece in place. This compares to a loss of 0.5 ppm CO observed when using the bag without the mouthpiece. All samples were loaded and analyzed with less than ten minutes storage time.

5.3.4.8 Effect of Concentrated Organic Compounds on Monitor and Prefilter Performance

Experiments were performed to determine possible interferences with CO measurements using compounds which might be found in breath samples. In an initial experiment, a 10 mL volume of neat (i.e., not in solution, undiluted) ethanol, acetone, methyl ethyl ketone, or propionaldehyde was placed in a small beaker. Headspace of the beaker was sampled using the GE monitor adjusted to a flow rate of 100 mL/min without the charcoal/Purafil® prefilter. The monitor did not respond to acetone and methyl ethyl ketone, but gave an immediate high response to ethanol and propionaldehyde. For these latter two compounds, the small, integral Purafil® filter within the GE monitor had turned a noticeable brown color.

The experiment was repeated with ethanol, propionaldehyde, and acetaldehyde using a charcoal/Purafil® prefilter. The breakthrough time and sample volume for each compound were determined for the prefilter using the GE monitor attached to a strip chart recorder. For ethanol, a baseline deflection or monitor response became noticeable after approximately 60 minutes, which is equal to a 6 L breakthrough volume. The Purafil® in the prefilter had started to turn brown before any detector response was recorded. Since this was the case, a color change in the Purafil® could be used as the criterion for replacing the filter during field sampling.

Propionaldehyde appeared to instantaneously breakthrough the charcoal/Purafil® prefilter. However, the Purafil® did not discolor during this experiment. Since previous experiments with propionaldehyde had shown a brown discoloration of the Purafil® and aldehydes are unstable and tend to break down into other chemicals, the breakthrough response was attributed to a contaminate in the propionaldehyde. Because of these spurious results acetaldehyde was tested. The filter appeared to retain acetaldehyde for approximately 20 minutes before the Purafil® discolored and the monitor gave an off-scale response.

These experiments were performed under "worst case" conditions by loading the prefilter with high concentrations of organic compounds where breakthrough should result from saturating the filter rather than from a chromatographic effect. Even under these conditions, the filter was effective and should be adequate for field testing of breath samples.

5.3.4.9 Method Precision

In a final experiment, the precision of the method was evaluated using eight nonsmoking subjects who gave four breath samples each. All samples were collected in the CBH bags using disposable mouthpieces and analyzed on a GE CO monitor, Model 3. The CO levels analyzed ranged from 1.9 to 3.8 ppm with coefficients of variation from 0 to 16 percent. Except for one individual, all CVs were 5% or lower. The final results are listed in Table 5.3.10.

The range of concentrations examined during the laboratory evaluation of method precision were necessarily low due to use of samples from non-smoking subjects. A measure of the method precision at higher concentration levels can be inferred from the analysis of laboratory and field control samples performed during the field sampling phase of the project. The means of analyses of laboratory and field control samples at 9.98 ppm were 9.46 ± 0.45 ppm (± one standard deviation) and 9.51 ± 0.50 ppm, respectively. The means for analyses of samples at 39.6 ppm were 39.3 ± 0.35 ppm and 39.4 ± 0.58 ppm, respectively.

5.3.4.10 Analysis Procedure Used During Field Sampling

Based on the result of the method development and evaluation, a Standard Operating Procedure entitled "Collecting and Sampling Alveolar Carbon Monoxide" was written and has been included herein as Appendix H. This SOP was used as the analysis procedure during field monitoring with one exception concerning the preparation of standard atmospheres for monitor calibration. Analysis data were

Table 5.3.10 Breath Measurements for Non-Smoking Subjects

Subject	Measured [CO] ppm ± S.D. (C.V.)
1	1.9 ± .1 (5)
2	2.7 ± .1 (4)
3	2.7 ± .1 (4)
4	1.9 ± .1 (5)
5	1.9 ± .1 (5)
6	2.1 ± .1 (5)
7	3.8 ± 0 (0)
8	2.4 ± .4 (16)

recorded on the data sheet depicted in Figures 5.3.6 and 5.3.7. The exception to the SOP is discussed below.

The calibration standards for the breath analysis consisted of CO in synthetic air cylinder gases at CO levels of 0.0, 3.59, 9.98, and 39.6 ppm. Like the standards for the ambient analyses, these gases contained no carbon dioxide or water vapor. They were analyzed for CO and oxygen content by the manufacturer and verified for CO content against NBS-tracable standards at RTI before being used in the field. At the beginning of the field analyses, however, it was demonstrated that the routine transition from "wet" breath samples (i.e., samples at essentially 100 percent relative humidity) to "dry" zero or calibration matrices (or vise-versa) induced a nonreproduceable zero-level response from the CO-3 monitor. These phenomena were attributed to retention and subsequent release of water vapor by the prescrubber column during sample/standard transitions. This led to the imposition of a water vapor gradient on the monitor which lasted for 5-10 minutes and produced the nonreproduceable zero responses. It was decided that wet zero and calibration matrices would be used for the analyses. The humidification of the zero air was accomplished by placing an impinger containing deionized water between the zero air supply and the zero air manifold. The humidified standards were prepared by filling sampling bags to which 1-2 drops of water had been added with the various calibration matrices. These bags were set aside for approximately 30 minutes while the added water evaporated into the calibration gas. The use of the wet zero and calibration matrices eliminated the nonreproduceable zero response and it is recommended that this modification be added to the SOP before it is again utilized in field sampling.

5.4 Data File Creation and Descriptions

5.4.1 Descriptions of Raw Data Files

Data for the Washington, D.C. carbon monoxide exposure study consisted of four basic types (exclusive of the sampling information, described in Section 5.1). These four data files are briefly described below.

File A: Personal Exposure Monitor (PEM) Data. CO exposure levels from the PEM were obtained for four kinds of samples:

CO EXPOSURE STUDY, WASHINGTON, DC
BREATH SAMPLE DATA SHEET

SAMPLE DATE __________ ANALYSIS DATE __________ ANALYST __________

P.I.D. #	CO LEVEL (PPM)
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐

if data continued on back: ☐

Figure 5.3.6 Breath Sample Data Sheet, Side 1

BREATH SAMPLE DATA SHEET (Continued)

P.I.D. #	CO LEVEL (PPM)
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐
☐☐☐☐☐☐☐	☐☐☐.☐

Figure 5.3.7   Breath Sample Data Sheet, Side 2

(1) routine samples -- 774 data records -- for CO measurements on persons selected into the sample,

(2) duplicate samples -- 60 data records covering 28 person-days -- for CO measurements on interviewers carrying multiple PEMs,

(3) colocated samples -- 10 data records -- for PEMs monitoring CO levels in the vicinity of a fixed-site monitoring station,

(4) EPA audit samples -- 9 data records.

This file thus consisted of 853 data records.

In addition to sample-identifying information, each record indicated the time and value of a series of PEM measurements. The CO measurements were generated as automatic recordings on the hour or as manual readings when activities of sample members changed. The measurements represented the average (integrated) CO level during the preceding time interval (i.e., since the beginning of the hour or since the last manual entry). On the raw data file, the CO data were recorded in raw units. However, the slope and intercept, as well as a validity check code for the straight-line calibration curve, were available on each record so that CO levels could be converted to parts per million (ppm). The contents of this file are shown in Exhibit 5.4.1. For the routine samples, the time period during which the PEM was in the presence of the sample member was identifiable only through the diary data.

File B: Activity Diary Data. Diary data consisted of (a) identification data (person and monitor ID numbers, and starting and ending times and dates); and (b) information on each activity. The latter included:

- activity code
- location code
- address information
- mode of travel (if in transit)
- indicator for whether a garage was attached to building (if indoors)
- indicator for whether a gas stove was in use (if indoors)
- indicator for whether smoker(s) were present.

Exhibit 5.4.1 Contents of File A (PEM Data)

Variable	Description
BATCH	Batch Number
PID	Person or sample identification number
MONID	Monitor ID number
SAMPDATE	Date of sample (month/day/year)
VALCODE	Validity check code for calibration curve
APPINTRC	Intercept of calibration curve
APPSLOPE	Slope of calibration curve
THR1-THR96	Hour of PEM reading (up to 96 readings)
TMIN1-TMIN96	Minute of PEM reading (up to 96 readings)
C1-C96	CO level from PEM (up to 96 readings)

Exhibit 5.4.2 shows the data codes used for the above variables. The raw data file of diary data contained 16,820 data records (i.e., activity segments) for 917 persons.

File C: Breath CO-Level Data. The "breath" CO data file, in its initial form, consisted of 1,390 data records, which were distributed as follows:

(1) 793 routine samples from sample members

(2) 110 duplicate routine samples (some of these represent the only usable breath measurement for some individuals, even though they were coded as duplicates)

(3) 12 children's breath samples (from children in households of study participants)

(4) 14 suspected smoker's breath samples

(5) 61 quality control samples (blank, field control, and laboratory air samples).

The information on each record consisted of the CO level (in ppm), as well as sample identification data and dates of sampling and chemical analysis.

File D: Questionnaire Data. In addition to providing PEM and breath measurements and the Activity Diary data, study participants were asked to furnish information on their homes, typical commuting activities, etc. through a Study Questionnaire (see Appendix C). Data from this questionnaire were incorporated into a data file; the file contained data for 916 persons.

Exhibit 5.4.3 shows the variables on this file. Only a few of the pertinent variables in these data records were utilized in the analyses reported herein due to time and cost constraints (additional use of the questionnaire data are recommended for future analyses). These included the following:

- Questions 20 and 29A -- variables 13 and 69 -- were utilized to classify persons into three occupational exposure categories:
  (1) "doesn't work outside home";
  (2) "works outside home -- low exposure"; or

Exhibit 5.4.2 Description of Codes for Variables Appearing in File B (Activity Diary Data)

Activity Codes:

Act	Description
1	transit, travel
2	work, business meeting
3	cooking
4	laundry
5	inside house - chores
6	outside house - chores
7	errands, shopping, etc.
8	personal activities
9	leisure activities
11	sleeping
12	school, study
13	eating, drinking
14	sports and exercise
15	church, political meetings, etc.
16	inside house - misc.
17	in parking garage or lot
18	outside, not otherwise specified
19	doctor or dentist office
87	start diary
88	end diary
89	any other activity
90	no activity entry
91	activity entry not legible
92	uncertain of applicable activity code

Location of Activity

Loc	Description
0100	in transit
0200	indoors - residence
0300	indoors - office
0400	indoors - store
0500	indoors - restaurant
0661	indoors - garage
0662	indoors - auditorium, sports arena, etc.
0663	indoors - church
0664	indoors - shopping mall, theater at mall
0665	indoors - school, school gym
0666	indoors - hospitals
0667	indoors - laboratories
0668	indoors - not specified
0669	any other indoor location
0700	outdoors - within 10 yards of road or street
0881	outdoors - garage, parking lot
0882	outdoors - construction site
0883	outdoors - residential area
0884	outdoors - park, sports arena, playground
0885	outdoors - gas station
0888	outdoors - not specified
0889	any other outdoor location
0900	uncertain
9800	missing

Exhibit 5.4.2 (cont'd)

Mode of Travel

Modetrav	Description
0100	walking
0200	car
0300	bus
0400	truck
0500	train/subway
0661	jogging
0662	bicycle
0663	motorcycle
0664	van
9500	bad data
9600	multiple response
9800	missing

Smokers Present?

Smokers	Description
•	missing
1	yes
2	no
3	uncertain

Garage Attached to Building?

Garage	Description
•	missing
1	yes
2	no
3	uncertain

Gas Stove in Use?

Gasstove	Description
•	missing
1	yes
2	no
3	uncertain

Exhibit 5.4.3 Contents of File D (Questionnaire Data)

#	Variable	Label
45	AIRCONDT	Q8 Air Cond used in living quarters
74	AREAAIRC	Q24 Enclosed area air-conditioned
75	AREAFANS	Q25 Fans used in enclosed area
76	AREASMOK	Q26 Smokers present in enclosed area
39	ATTICFAN	Q6A Attic fan used in living quarters
67	AUTOYEAR	Q18 year of auto most used in normal week
1	BATCH	
47	BUSGARGE	Q10A Living quarters within 3 blocks bus garage
108	COMMENTS	Comments
52	COMMJT3X	Q11 Commute to work, school, etc., 3X/week
106	DATEDA	Day
105	DATEMO	Month
107	DATEYR	Year
72	DESCSPAC	Q22Oth Describe other enclosed area
50	ELECPLNT	Q10D Living quarters near electric or steam plant
71	ENCLSFAC	Q22 Enclosed area at work most of time
70	ENCLWORK	Q21 Some part worktime in enclosed area
35	EXTRAINS	Q5C Extra insulation
4	FINUMBER	FI Number
25	FIREPLAC	Q4A Fireplace used in living quarters
8	FRMINUT1	Q14B1 Minutes traveling for commute
9	FRMINUT2	Q14B2 Minutes traveling for commute
10	FRMINUT3	Q14B3 Minutes traveling for commute
60	FRMODES1	Q14A1 Mode transportation for commute
62	FRMODES2	Q14A2 Mode transportation for commute
64	FRMODES3	Q14A3 Mode transportation for commute
61	FRSMOKR1	Q14C1 Smokers present during commute
63	FRSMOKR2	Q14C2 Smokers present during commute
65	FRSMOKR3	Q14C3 Smokers present during commute
46	GARAGEAT	Q9 Garage attached or in structure
29	GASDRYER	Q4F Gas clothes dryer in living quarters
27	GASFRUNC	Q4C Gas furnace used in living quarters
30	GASKERHT	Q4G Gas or kero. space heater in living quarters
28	GASRANGE	Q4D Gas cookstove used in living quarters
101	HOUMATER	FIUSA housing construction material
103	HOUSTYPE	FIUSB type of housing structure
48	HVVEHDEP	Q10B Living quarters near heavy vehicle depot
19	INGARMIN	Q34 Minutes spent in indoor garage
84	KINDBUSN	Q29B Kind of business employed in
13	KINDWORK	Q29A Occupation
87	LEISACT1	Q32A1 Leisure activity
89	LEISACT2	Q32A2 Leisure activity
91	LEISACT3	Q32A3 Leisure activity
93	LEISACT4	Q32A4 Leisure activity
95	LEISACT5	Q32A5 Leisure activity
88	LEISPLA1	Q32B1 Place of leisure activity

Exhibit 5.4.3 (continued)

90	LEISPLA2	Q32B2 Place of leisure activity
92	LEISPLA3	Q32B3 Place of leisure activity
94	LEISPLA4	Q32B4 Place of leisure activity
96	LEISPLA5	Q32B5 Place of leisure activity
14	LEISTIM1	Q32C1 Time spent in leisure activity
15	LEISTIM2	Q32C2 Time spent in leisure activity
16	LEISTIM3	Q32C3 Time spent in leisure activity
17	LEISTIM4	Q32C4 Time spent in leisure activity
18	LEISTIM5	Q32C5 Time spent in leisure activity
21	LIVQALLP	Q3A Number of people in living quarters
23	LIVQCIGT	Q3C Cigarette smokers in living quarters
20	LIVQKIND	Q1 Living quarters description
24	LIVQSMOK	Q3D Number cigarette packs used in week
3	LIVQSQFT	Q2 Square feet in living quarters
22	LIVQTOBA	Q3B Tobacco smokers in living quarters
43	MAINHEAT	Q7 Main type of heating system
44	MAINHTSP	Q7SP Specify other type main heat
79	NRBUSGAR	Q28A Work 3 blocks from bus garage
82	NRELPLNT	Q28D Work 3 blocks from elec. op. steam plant
80	NPHVDEPO	Q28B Work 3 blocks from heavy vehicle depot
81	NROPBURN	Q28C Work 3 blocks from open burn site
83	NRSMPLNT	Q28E Work 3 blocks from heavy smoke emitter
49	OPENBURN	Q10C Living Quarters near site of open burning
41	OTHERFAN	Q6C Other type fan used in living quarters
37	OTHERGAD	Q5E Other energy-saving device
31	OTHERGAS	Q4H Other gas appliance
42	OTHFANSP	Q6CSP Specify other type fan
38	OTHGADSP	Q5ESP Specify other energy-saving device
32	OTHGASSP	Q4HSP Specify other gas appliance
102	OTHMATER	FIUSAOTH Describe other housing material
104	OTHSTYPE	FIUSBOTH Describe other housing structure
86	OUTDWKWK	Q31 Hours work outdoors in week
69	OUTSIJOB	Q20 Full- or part-time job outside home
66	PASSGHRS	Q17 Passenger for how many hours weekly
2	PID	
99	RESP_AGE	Q35B Respondent's age
100	RESP_EDU	Q35C Respondent's education level
98	RESP_SEX	Q35A Respondent's sex
59	SAMEMODE	Q13 Return home same travel mode
97	SHOPPARK	Q33 Indoor parking on shopping trips
73	SIZESPAC	Q23 Size of enclosed area at work
51	SMOKPLNT	Q10E Living quarters near heavy smoke emitter
36	SPDAMPER	Q5D Special dampers stove/fireplace
34	STORMDOR	Q5B Storm doors
33	STORMWIN	Q5A Storm windows
11	TIMEARRI	Q15 Time arrive at destination
12	TIMEDEPA	Q16 Time depart for home
5	TOMINUT1	Q12B1 Minutes traveling for commute
6	TOMINUT2	Q12B2 Minutes traveling for commute
7	TOMINUT3	Q12B3 Minutes traveling for commute

Exhibit 5.4.3 (continued)

53	TOMODES1	Q12A1 Mode transportation for commute
55	TOMODES2	Q12A2 Mode transportation for commute
57	TOMODES3	Q12A3 Mode transportation for commute
54	TOSMOKR1	Q12C1 Smokers present during commute
56	TOSMOKR2	Q12C2 Smokers present during commute
58	TOSMOKR3	Q12C3 Smokers present during commute
68	WEEKLHRS	Q19 Hours spent in auto in average week
40	WINDOFAN	Q6B Window fan used in living quarters
78	WKHEATSP	Q27SP Specify other type heating system
26	WOODSTOV	Q4B Woodstove used in living quarters
77	WORKHEAT	Q27 Main heating system at work place
85	WORKWEEK	Q30 Number hours in normal work week

(3) "works outside home -- high exposure". (The occupations identified as having high potential exposure were: crane, derrick, or hoist operator; automobile mechanic; garage or gas station worker; machine operator; bus driver; taxi driver/chauffeur; truck driver; construction laborer; warehousmen; cook; airline host/hostess; firemen; police/detective - see Appendix K.)

- Question 4D -- variable 28 -- was used to classify persons according to the type of stove used in their home: (1) vented gas stove, (2) unvented gas stove, or (3) other (non-gas).
- Questions 11 and 17 -- variables 52 and 66 -- were utilized to classify individuals according to commuting status and amount of travel: (1) non-commuter, or (2) commuter with total travel of 0-5 hours per week, 6-10 hours per week, 11-15 hours per week, or more than 15 hours per week.

5.4.2 Creation of Analysis Files

Three analysis files were created: (1) the basic analysis file (BAF); (2) the activity analysis file (AAF); and (3) the duplicate measurement file (DMF).

These files and their construction are described, respectively, in subsections 5.4.2.1, 5.4.2.2, and 5.4.2.3.

5.4.2.1 Creation of the Basic Analysis File (BAF).

A first step in creating the BAF involved the examination of the sampling dates and times as reported in the Activity Diary (i.e., File B). Where necessary, corrections were made to these start and stop times (e.g., by comparison to the PEM data) and dates (e.g., by correcting the year from 1982 to 1983 in some cases).

The next step in creating the BAF was to perform edit checks on the PEM data (File A). The 774 routine samples were first examined to determine those individuals with unusable or insufficient data. This involved eliminating 41 samples for which the calibration data were questionable (validity codes = 4); eliminating 15 samples with less than an 18-hour monitoring period (it was felt, since 8-hour CO maximums were to be computed, that at least 18 hours of data should be available for each sample respondent); eliminating 5 samples for which no diary data (and hence no start or stop times) were available; and eliminating one sample due to misassignment of the PEM (i.e., the wrong person had been monitored). This left 712 sample members whose PEM information, after further editing, was considered acceptable.

The editing of the PEM data involved identifying and resolving the following types of potential problems:

(1) out-of-range hour and/or minute values
(2) times not in the proper sequence
(3) missing times and/or missing CO values
(4) large CO values (e.g., over 20 ppm).

The PEM information was listed and examined manually for any individual whose data exhibited any of the above. When deemed necessary, the hard-copy field data and/or diary data were consulted in order to make the appropriate resolutions in the time and/or CO values.

After this editing, the PEM CO data values for each of the 712 individuals were time weighted to produce hourly CO values. The CO values were converted to ppm units by using the slope and intercept values for the calibration curve. Any CO level less than .05 ppm was set equal to .05 ppm. The hourly values were constructed only for those hours for which the PEM data indicated coverage of the entire hour. This hourly data file contained from 18 to 26 hourly CO values, depending upon the particular start and stop times of the particular sample (or in some cases, the time at which a monitor failure occurred). The number of samples, by hour of day, is shown in Table 5.4.1. As these results indicate, the hourly data do not fully cover a 24-hour time period for all 712 sample members. Coverage was especially lacking during the 6-9 p.m. time period when sampling was begun or terminated. The distributions of the number of hourly CO values per sample and of the day of sampling are shown, respectively, in Tables 5.4.2 and 5.4.3.

After editing of the routine-sample PEM data and construction of the hourly CO values, several additional variables were constructed and augmented onto each record of the file. These were the following:

(1) the mean hourly CO concentration (ppm);
(2) the maximum hourly CO concentration (ppm);
(3) the maximum 8-hour CO concentration (ppm); and

Table 5.4.1 Number of Routine Samples With Valid Hourly CO Values, By Hour of Day

Hour (ending)	Day 1*	Day 2	Day 1 or Day 2
01	--	711	711
02	--	712	712
03	--	712	712
04	--	712	712
05	--	712	712
06	--	712	712
07	--	712	712
08	--	712	712
09	--	711	711
10	--	712	712
11	--	712	712
12	--	712	712
13	--	712	712
14	--	712	712
15	--	708	708
16	--	707	707
17	--	702	702
18	5	666	670
19	28	548	570
20	158	284	426
21	469	85	540
22	664	9	668
23	708	--	708
24	712	--	712

* Day 1 is the day that sampling began (in the evening); day 2 is the following day.

Table 5.4.2 Distribution of the Number of Hourly CO Values Per Sample

Number of Hourly CO Values Per Sample	No. of Samples
18	4
19	3
20	6
21	27
22	96
23	374
24	170
25	23
26	9
Total	712

Table 5.4.3 Distribution of Sampling Dates, by Month and Day of Week

Sampling Days	Nov. 1982	Dec. 1982	Jan. 1983	Feb. 1983	Total
Sun - Mon	26	19	40	15	100
Mon - Tues	36	37	47	20	140
Tues - Wed	13	30	35	37	115
Wed - Thurs	12	26	29	22	89
Thurs - Fri	13	29	41	24	107
Fri - Sat	6	27	39	23	95
Sat - Sun	13	14	24	15	66
	119	182	255	156	712

(4) the beginning hour (index) of that 8-hour period for which the maximum 8-hour CO concentration occurred.

The mean (maximum) hourly CO concentration for a particular sample individual was based upon averaging (maximizing) over all of the hourly CO values that were available. The third variable was determined in the following manner. Let f and ℓ denote the hour index of the first and last hourly CO values available for a particular sample. The following 8-hour averages were computed:

$$Y_a = \sum_{i=a}^{a+7} X_i I_i / n_a \qquad a=f,(f+1), \ldots, (\ell-7)$$

where I_i = 0 if the hourly CO value for hour index i is missing
= 1 otherwise;

X_i = the hourly CO value in ppm for hour index i, and

$$n_a = \sum_{i=a}^{a+7} I_i$$ = number of non-missing hourly CO values in the 8-hour interval beginning at hour "a".

The maximum 8-hour CO concentration was then determined as the maximum Y_a value for which $n_a \geq 6$ (i.e., at least six hourly values were required during a consecutive eight-hour period in order for a Y_a value to be considered as an "8-hour average"). The fourth variable indicated the beginning hour index of the maximum 8-hour CO concentration period -- i.e., the value of "a".

The above four variables were derived exclusively from the hourly data. In addition, variables from other sources were incorporated into the BAF. These variables included the following:

(1) the set of variables described for File D (questionnaire data) in Section 5.4.1

(2) the breath CO level (averaged over the duplicate readings in those cases where an individual provided two breath samples)

(3) a variable indicating those dates for which fixed-site monitors in the DC area showed high CO levels (based on information furnished by EPA), and

(4) the pertinent sample design variables and adjusted sampling weights.

The sample design variables included the person-level weighting class indicator, and the "analysis stratum" and "analysis PSU" variables described in Section 5.1. Three sampling weights were constructed:

(a) the adjusted sampling weight (see Section 5.1), which is appropriate for analyses in which all 712 individuals provide data on the relevant analysis variable(s);

(b) the diary-activity adjusted sampling weight, which is appropriate for analysis of diary activity data (available for only 705 of the 712 sample members); and

(c) the breath-level adjusted sampling weight, which is appropriate for analysis of the breath CO concentration data (available for only 659 of the 712 sample members).

The total of the adjusted sampling weight for the person-level weighting class was also included on the file so that additional weight adjustments could be readily made. Such adjustments are needed, for instance, when estimating the mean CO level for some specific hours of the day since not all 712 individuals furnished such data (see Table 5.4.1).

Exhibit 5.4.4 shows the contents of the Basic Analysis File.

5.4.2.2 Creation of the Activity Analysis File (AAF)

The creation of the AAF first required that an extensive amount of editing be performed on File B (see Section 5.4.1). This involved the following:

(1) deletion of all activity segments associated with nonrespondents -- defined as those sample members not among the 712 who furnished sufficiently complete and valid PEM data (205 individuals and 3345 activity segments -- recall that monitor failure caused a substantial amount of CO data to be lost from sample members);

(2) deletion of all activity segments for seven additional individuals -- namely those having obviously incomplete diaries (7 individuals with a total of 28 activity segments);

(3) deletion of specific activity segments -- duplicate segments, segments with missing/invalid times, activities, etc. (50 segments);

Exhibit 5.4.4 Contents of Basic Analysis File

#	Variable	Label
43	APSU	Analysis PSU
44	ASTRATUM	Analysis stratum
7	AVC18	CO concentration for day 1, hour 17-18
8	AVC19	CO concentration for day 1, hour 18-19
9	AVC20	CO concentration for day 1, hour 19-20
10	AVC21	CO concentration for day 1, hour 20-21
11	AVC22	CO concentration for day 1, hour 21-22
12	AVC23	CO concentration for day 1, hour 22-23
13	AVC24	CO concentration for day 1, hour 23-24
14	AVC25	CO concentration for day 2, hour 00-01
15	AVC26	CO concentration for day 2, hour 01-02
16	AVC27	CO concentration for day 2, hour 02-03
17	AVC28	CO concentration for day 2, hour 03-04
18	AVC29	CO concentration for day 2, hour 04-05
19	AVC30	CO concentration for day 2, hour 05-06
20	AVC31	CO concentration for day 2, hour 06-07
21	AVC32	CO concentration for day 2, hour 07-08
22	AVC33	CO concentration for day 2, hour 08-09
23	AVC34	CO concentration for day 2, hour 09-10
24	AVC35	CO concentration for day 2, hour 10-11
25	AVC36	CO concentration for day 2, hour 11-12
26	AVC37	CO concentration for day 2, hour 12-13
27	AVC38	CO concentration for day 2, hour 13-14
28	AVC39	CO concentration for day 2, hour 14-15
29	AVC40	CO concentration for day 2, hour 15-16
30	AVC41	CO concentration for day 2, hour 16-17
31	AVC42	CO concentration for day 2, hour 17-18
32	AVC43	CO concentration for day 2, hour 18-19
33	AVC44	CO concentration for day 2, hour 19-20
34	AVC45	CO concentration for day 2, hour 20-21
35	AVC46	CO concentration for day 2, hour 21-22
45	BRCO	Breath CO concentration
48	BWEIGHT	Breath analysis weight
55	CMUTXHRS	Variable derived from Q11 and Q17
52	COMMUT3X	Q11 Commute work, school, etc., 3X/week
56	DAYOFWK	Day of week
47	DWEIGHT	Diary analysis weight
46	FWEIGHT	Field data analysis weight
49	FWTT	Total of FWEIGHT within PWTCLASS
51	GASRANGE	Q4D gas cookstove used in living quarters
6	HICODAY	High CO day indicator
50	KINDWORK	Q29A Occupation
37	MAXHRC	Maximum hourly CO concentration
39	MAX8HC	Maximum 8-hour CO concentration
38	MEANHRC	Mean hourly CO concentration
36	NHRC	Number of hourly CO values
53	PASSGHRS	Q17 Passenger for how many hours weekly

Exhibit 5.4.4 (continued)

1	PID	Check Digit ID
42	PWTCLASS	Person-level weight class
2	SAMPDATE	Date of sample (day 1, mmddyy)
57	TIMEWEEK	Weekday, weekend indicator
4	TSTART	Start time for sample (from diary)
5	TSTOP	Stop time for sample (from diary)
54	TYPEXPOS	Type of exposure
40	T8HSTRAT	First hour of 8-hour maximum CO
3	VALCODE	Validity code for claibration data
41	WTCLASS2	Final weighting class

(4) corrections of sampling dates (15 individuals);

(5) corrections of start or stop times of the sampling period (4 individuals);

(6) revisions in activity codes (282 segments);

(7) revisions in location codes (77 segments); and

(8) revisions in activity start times originally appearing as missing, partially missing, out-of-range or out-of-sequence (90 segments).

With the exception of item (1), all of the above items required at least some manual examination of the data, including in some cases review of the actual hard-copy diary data and/or of the PEM time values. This process took considerable staff time and lasted for several weeks.

The need for the manual examination of the data was largely due to potential inconsistencies in the location and activity codes. Some of these inconsistencies were resolved on a case-by-case basis, whereas some were resolved by establishing (and subsequently programming) a set of "consistency rules". In both cases, the location codes were generally regarded as being more accurate than the activity codes, since the activity codes were developed from a totally open-ended question (i.e., apart from instructions given to the study participants, they were permitted to provide activity descriptions in their own words and from their own perspective -- see Appendix C, Figures 4 and 5). A major exception to this was when both the activity code and the address information indicated that the activity was "in transit". The programmed "consistency rules", which in some cases made use of the address information provided in the diary, are shown below:

Original Codes*			Revised Codes**	
Activity	Location	Address Indicators***	Activity	Location
5	700	all	6	U
5	800-889	all	6	U
all	694-698	all	U	668
all	100	≠(1,0,0)	1	U
90-92	200-669	all	16	U
90-92	700-889	all	18	U
7	missing	(1,0,0)	U	400
1	all	(0,1,1)	U	100
4,16	883	all	U	668
5	300	all	U	668
7	200	all	U	668
15	700	all	18	U
16	881	all	U	661

* See Exhibit 5.4.2 for definitions of activity and location codes.

** U = unchanged (i.e., same as original code).

*** As illustrated in Figures 4 and 5 of Appendix C, the first address field should have been completed only for non-transit activities. Both the second and third address fields should have been completed if the activity was "in transit". The three address indicators are defined as (X_1,X_2,X_3) where X=0 if the i^{th} address is blank, and as $X_i=1$, otherwise.

A second major reason for needing a manual examination of a large portion of the diary information was the recognition of the fact that participants' omissions of diary entries (i.e., changes in activities) could potentially lead to serious biases in the study results. That such situations actually occurred in the raw diary data are clearly illustrated by the fact that only 463 of the 705 diary-respondents entered "eating, drinking" as an activity during their sampling period (at least 18 hours). Based upon the manual examination of a large number of individuals' diary data, it was clear that many of these types of data anomalies occurred due to the open-ended nature of the activity descriptions (i.e., respondents were simply allowed to describe their activities). Some respondents provided detailed activity descriptions whereas others furnished vague or general descriptions that may have encompassed several "activities" (e.g., for some respondents, the "eating, drinking" activity may have been subsumed under the activity "inside house - miscellaneous").

At the data editing/processing stage, little could be done to circumvent or ameliorate the problem indicated in the paragraph above. However, those individuals exhibiting extremely "long" activities were scrutinized in more detail. ("Long" depends, of course, upon the particular activity.) This detailed manual examination of the diary data led to (a) the decision to delete all data segments for those seven individuals who had been extremely vague in providing activity descriptions or who had been extremely negligent in providing a complete activity pattern (i.e., those with major omissions in their diary information); and (b) the decision that all activity segments that were likely to have included a sleep period should be recoded to reflect this "fact". (It should be noted that some of the descriptions of activities in the diary actually included such multiple activities -- e.g., "studied and slept.")

The recoding of those activities containing a suspected sleep period was made possible by the fact that sleeping is generally a long-duration activity that occurs at roughly the same time for most individuals. Such duration and regularity does not occur for other activities (e.g., eating) so that additional recodings of this type were not feasible.

At the beginning of this subsection it was indicated that 282 activity recodes had been made; of these, 167 arose from the manual recodes and activity/location consistency checks previously described, and 115 were the result of recodings of activities to include suspected sleep periods. It should be emphasized that the latter recoding was carried out in such a manner that identification of the original activity code was still possible. In particular, if A represents the original activity codes (see Exhibit 5.4.2), then the recoded value, A*, was determined as

$$\begin{aligned} A^* &= A + 20, && \text{if } 1 \le A \le 19 \\ A^* &= 77 && \text{if } A = 87. \end{aligned}$$

This permitted these segments to be utilized in various ways during the analysis phase.

At this point, the AAF contained 13,398 activity segments (for 705 sample members). The next step in creating the final AAF involved a machine comparison of the activity times entered in the diaries with the times entered on the PEMs. The following results were obtained:

(a) Of the 13,398 segments, exact matches between the diary and PEM times were found for 11,356 segments.

(b) Of the remaining 2042 segments, a near match in the two times (within 2 minutes) was found for 1022 segments.

(c) Of the remaining 1020 segments, 214 cases were found for which the same number of PEM and diary entries occurred within an hour, even though no PEM time could be found that matched the diary time (within 2 minutes).

(d) Of the remaining 806 non-matched cases, 68 occurred due to lack of PEM data during the period of interest.

Based upon the above comparisons between the PEM and diary times, two rules were adopted and implemented for updating the diary activity times. These rules were:

1. If the diary and PEM data indicated the same number of activities within a given hour, then the times from the diary were replaced by the times from the CO monitor.
2. If rule 1 did not apply, but a diary time and a PEM time matched within 2 minutes, then the diary time was replaced with the time from the monitor.

The results of the above-described updating of the diary times are summarized in the table below, which shows the number of activity segments falling into various categories:

Characteristic of Activity Start Time	Total No. of Segments	Segment Characteristic: Degenerate Time Interval	No CO Data Available	Partial CO Data Available	Full CO Data Available	Partial or Full CO Data Available
Time Match Exact - No Need to Update	11,356	650	0	32	10,674	10,706
Time Match w/in 2 min. - Time Updated (Rule 2)	1,022	50	0	2	970	972
Time Not Matched w/in 2 min. - Time Updated (Rule 1)	214	3	0	1	210	211
Time Not Matched w/in 2 min. - Time Not Updated	806	9	68	12	717	729
	13,398	712*	68	47	12,571	12,618

* Time intervals of 0 minutes duration; 607 of the 712 cases represent "start-diary" or "end-diary" activities (i.e., activity codes 87 or 88).

The last column in the above table indicates those activity segments for which a corresponding CO concentration level could be constructed from the PEM data.

The final step in creating the AAF was to determine these CO levels and to augment them onto the file. These were computed by time-weighting the PEM CO measurements over the time period associated with the given activity segment (or, in the 47 cases having only partial CO data, over that portion of the activity time interval for which the CO data were present).

The final AAF, unlike the BAF described in the previous subsection, cannot be used directly for most statistical analyses -- i.e., additional processing prior to the analysis is required (in order to augment sampling weights, revise codes, aggregate over an individual's segments, etc.). Since the additional data processing on the AAF that must be carried out prior to statistical analysis depends upon the particular analysis, this processing is considered a part of the analysis and is therefore not discussed further in this subsection.

5.4.2.3 Creation of the Duplicate Measurement File (DMF)

File A, as described in Section 5.4.1, provided the source data for the DMF. The 60 data records in this file corresponding to the duplicate samples (from interviewers with multiple PEMs) were first extracted. A printout of these data was produced and manually screened for timing errors. Several of the readings were discarded and several time corrections were made. The CO values were then time-weighted to produce hourly CO values. A file containing these hourly values -- the DMF -- was then created; a record was generated for each hour and PEM. The file contained information on the following variables:

PID	sample ID number (identifies person and PEM)
HOUR	hour index
CONC	hourly CO concentration
PERSON	code identifying interviewer/sample date
REP	=1 for first PEM; =2 for second PEM; etc.

The DMF contained a total of 1539 hourly CO values which covered 28 interview-"days" and a total of 724 unique interviewer-hours. At least two hourly "readings" were available for 689 of the 724 hours.

6. RESULTS AND DISCUSSION

6.1 Survey Design Results

6.1.1 Household Screener Statistical Analysis

Gas household appliances and certain sources of home heating are considered producers of carbon monoxide. The following related questions of interest were asked of a knowledgable household member, and analyzed for each household:

Is there

a. a fire place which is used?
b. a wood stove?
c. a gas furnace?
d. a gas cooking stove?
e. a gas hot water heater?
f. a gas clothes dryer?
g. a gas or kerosene space heater?
h. any other gas appliances?
i. an attached garage, or a shared, multi-family garage?

Estimates from these items are presented in Tables 6.1.1 through 6.1.8. These results are based on successful interviews from 4394 households in the Washington, D.C. metropolitan area, and 2128 households from the Denver metropolitan area. The population estimate for the number of households in the two sites for the time the survey was conducted is 953,714 for Washington and 345,163 for Denver. Due to the fact that no item-level nonresponse adjustments or item imputations were made, these estimates are underestimates of the true total (i.e., in the tables there is a "Not Known" category). However, the difference between the estimates and the true totals are believed to be small.

For each data item, a separate category (namely, "not known") was created to represent those households for which the respondent or interviewer was uncertain whether a particular appliance, etc. existed.

As an example, the study determined that there are an estimated 467 households in Washington, D.C. (Table 6.1.1) for which the screening questionnaire did not ascertain whether a fireplace was being used.

In terms of home heating, about 33 percent of the Washington area households have fireplaces in use and roughly 67 percent do not (Table 6.1.1). Fewer than 30 percent of Denver households have fireplaces (Table 6.1.1).

As expected, there are fewer homes utilizing wood stoves - an estimated 4 percent for the Washington area and 6 percent for Denver (Table 6.1.2). Among the four means of home heating, the gas furnace is clearly the most common heating source. This is indicated in Table 6.1.3: 56 percent or 532,347 households use gas furnaces in the Washington area and 71 percent or 245,902 households use gas furnaces in the Denver area. The percent of households using gas or kerosene space heaters is similar to those using wood stoves, about 3 percent for Washington and 5 percent for Denver (Table 6.1.4).

Statistical results for the usage of gas appliances are presented in Tables 6.1.5 through 6.1.8. An estimated 64 percent or 609,029 households in Washington, DC, and 25 percent or 85,542 households in Denver use gas cooking stoves (Table 6.1.5). Gas hot water heaters serve 542,855 or 57 percent and 269,810 or 78 percent of households from the respective sites, Washington and Denver (Table 6.1.6). An estimated 191,803 households or 20 percent and 57,402 households or 17 percent use gas clothes dryers in their homes (Table 6.1.7). Other gas appliances are seldom used. This is evident in Table 6.1.8: approximately 2 percent and 0.2 percent of Washington and Denver metropolitan area households use other gas appliances, respectively.

According to Table 6.1.9, a combined estimate of 207,719 or 22 percent of Washington area households have an attached garage or share a multi-family garage. This compares to a combined estimate of 120,460 or 35 percent for Denver area households.

6.1.2 Personal Item Statistical Analysis

As with most studies which involve a sample of households, there is some interest in specific attributes of the household members. In the CO Study a respondent was requested to answer several questions

Table 6.1.1 Estimated Number of Households Using a Fireplace

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	316,925	0.3323	103,211	0.2991
Standard Error	29,538	0.0301	16,030	0.0362
No	636,322	0.6672	241,629	0.7002
Standard Error	59,462	0.0302	18,608	0.0361
Not Known	467	0.0004	227	0.0006
Standard Error	193	0.0002	141	0.0004
Grand Total	953,714		345,068	
Sample Size	4,394		2,128	

Table 6.1.2 Estimated Number of Households Using a Wood Stove

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	37,721	0.0395	20,314	0.0588
Standard Error	6,858	0.0075	2,841	0.0089
No	915,382	0.9598	324,453	0.9400
Standard Error	64,623	0.0075	24,594	0.0089
Not Known	611	0.0006	396	0.0011
Standard Error	378	0.0003	184	0.0005
Grand Total	953,714		325,163	
Sample Size	4,394		2,128	

Table 6.1.3 Estimated Number of Households Using a Gas Furnace

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	532,347	0.5581	245,902	0.7124
Standard Error	40,943	0.0355	22,231	0.0379
No	391,130	0.4101	94,964	0.2751
Standard Error	52,169	0.0365	14,608	0.0376
Not Known	30,237	0.0317	4,297	0.0124
Standard Error	13,517	0.0146	1,246	0.0036
Grand Total	953,714		345,163	
Sample Size	4,394		2,128	

Table 6.1.4 Estimated Number of Households Using a Gas or Kerosene Space Heater

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	30,530	0.0320	18,352	0.0531
Standard Error	5,621	0.0050	4,480	0.0111
No	921,536	0.9662	326,152	0.9449
Standard Error	61,817	0.0050	22,301	0.0111
Not Known	1,649	0.0017	659	0.0019
Standard Error	444	0.0004	265	0.0007
Grand Total	953,714		345,163	
Sample Size	4,394		2,128	

Table 6.1.5 Estimated Number of Households Using a Gas Cooking Stove

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	609,029	0.6385	85,542	0.2478
Standard Error	49,353	0.0329	7,308	0.0245
No	344,329	0.3610	259,365	0.7514
Standard Error	41,033	0.0329	24,195	0.0245
Not Known	357	0.0003	256	0.0007
Standard Error	213	0.0002	160	0.0004
Grand Total	953,714		345,068	
Sample Size	4,394		2,128	

Table 6.1.6 Estimated Number of Households Using a Gas Hot Water Heater

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	542,855	0.5692	269,810	0.7816
Standard Error	37,564	0.0308	20,930	0.0332
No	361,036	0.3785	67,425	0.1953
Standard Error	50,113	0.0346	13,256	0.0331
Not Known	49,823	0.0522	7,928	0.0229
Standard Error	13,628	0.0152	1,175	0.0037
Grand Total	953,714		345,163	
Sample Size	4,394		2,128	

Table 6.1.7 Estimated Number of Households Using a Gas Clothes Dryer

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	191,803	0.2011	57,402	0.1663
Standard Error	17,316	0.0195	8,018	0.0179
No	737,472	0.7733	285,830	0.8281
Standard Error	64,529	0.0217	20,381	0.0178
Not Known	24,284	0.0254	1,931	0.0055
Standard Error	13,259	0.0142	724	0.0021
Grand Total	953,560		345,163	
Sample Size	4,393		2,128	

Table 6.1.8 Estimated Number of Households Using Other Gas Appliances

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	16,036	0.0168	782	0.0022
Standard Error	3,362	0.0037	293	0.0008
No	934,713	0.9800	344,019	0.9966
Standard Error	64,821	0.0038	24,659	0.0009
Not Known	2,966	0.0031	362	0.0010
Standard Error	704	0.0007	172	0.0005
Grand Total	953,714		345,163	
Sample Size	4,394		2,128	

Table 6.1.9 Estimated Number of Households Having an Attached Garage or Sharing a Multi-Family Garage

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Attached Garage	165,919	0.1740	108,934	0.3156
Standard Error	22,525	0.0191	11,188	0.0284
Multi-Family Garage	41,800	0.0438	11,526	0.0333
Standard Error	13,845	0.0153	3,919	0.0099
Neither	744,976	0.7812	222,199	0.6437
Standard Error	58,749	0.0250	18,870	0.0298
Not Known	862	0.0009	2,504	0.0072
Standard Error	426	0.0004	2,469	0.0070
Grand Total	953,557		345,163	
Sample Size	4,393		2,128	

on behalf of each individual living in the household. Below is the information asked for each individual:

a. sex
b. age
c. individual's relationship to head of household
d. whether individual presently smokes or uses tobacco in any form
e. whether individual is employed either full or part time
f. whether individual travels to and from work, school, or any other place at least 3 times a week
g. amount of time spent traveling one way when going any place at least 3 times per week.

Statistical results to follow are based on varying sample sizes due to missing data for individual questionnaire items. The number of responses was highest for the sex item: 11,545 for Washington, DC and 5,142 for Denver. No item-level nonresponse adjustments or imputations were made for two reasons. First, the item response rate was high for most items. Second, analysis of the screening data was considered to be less important than analysis of monitoring data. Instead of weight adjustments or imputations, the category "not known" is presented to represent those individuals for whom the respondent or interviewer could not determine a correct entry for any individual's attributes. Included in this category is a population estimate for the data item of interest. The statistical results of all personal item data are presented in Tables 6.1.10 through 6.1.16.

According to Table 6.1.10, an estimated 1.29 million people or 48 percent of the Washington metropolitan population are male. This compares to the 1980 Census which reports 1.33 million males or 48 percent in the same area (Table 6.1.11). Also, 1.38 million females or 52 percent are estimated from the CO Study results versus 1.44 million females or 52 percent from the 1980 Census. Neither of these statistics are expected to be exactly equal, primarily because of a population change from 1980 to 1983 and sampling variability. They are, however, approximately the same. When sex is disregarded, the CO Study results estimate the 1983 Washington metropolitan population to be 2.67 million

Table 6.1.10 Estimated Sex Distribution

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Male	1,286,056	0.4821	415,730	0.4739
Standard Error	133,431	0.0094	30,762	0.0091
Female	1,379,812	0.5173	460,836	0.5253
Standard Error	116,697	0.0094	39,728	0.0091
Not Known	1,329	0.0004	556	0.0006
Standard Error	483	0.0001	402	0.0004
Grand Total	2,667,197		877,122	
Sample Size	11,545		5,142	

Table 6.1.11 The Sex Distribution According to the 1980 Census

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Male	1,327,797	0.4805	380,479	0.4867
Female	1,435,308	0.5195	401,305	0.5133
Population Total	2,763,105		781,784	

Table 6.1.12 Estimated Age Distribution - Categorized According to the 1980 Census Definitions

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Under 18 Years	699,556	0.2677	227,112	0.2626
Standard Error	108,889	0.0197	27,009	0.0155
Between 18 to 64 Years	1,720,330	0.6583	564,554	0.6528
Standard Error	139,452	0.0150	46,137	0.0142
65 Years and Older	153,628	0.0587	67,091	0.0775
Standard Error	10,816	0.0055	5,959	0.0092
Not Known	39,405	0.0150	5,939	0.0068
Standard Error	7,320	0.0024	822	0.0010
Grand Total	2,612,919		864,695	
Sample Size	11,188		5,015	

Table 6.1.13 Age Distribution According to the 1980 Census

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Under 18 Years	721,170[1/]	0.261	197,171[2/]	0.2522[2/]
Between 18 to 64 Years	1,826,412[1/]	0.661	506,955[2/]	0.6484[2/]
65 Years and Older	215,523[1/]	0.077	77,658[2/]	0.0994[2/]
Population Total	2,763,105		781,784[2/]	

[1/] Estimated from proportions published in the 1980 General Population Characteristics for District of Columbia.

[2/] Estimated from proportions published in the 1980 General Population Characteristics for Colorado.

Table 6.1.14 Estimated Distribution of Relationship to Head of Household

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Head of Household	949,796	0.3549	346,637	0.3953
Standard Error	63,594	0.0126	24,712	0.0099
Spouse	554,922	0.2073	191,165	0.2180
Standard Error	49,274	0.0180	14,866	0.0105
Child of Head	891,611	0.3332	229,522	0.2617
Standard Error	151,940	0.0293	16,388	0.0144
Other Relation	126,729	0.0473	30,882	0.0352
Standard Error	20,789	0.0088	3,969	0.0053
No Relation	147,567	0.0551	41,584	0.0474
Standard Error	26,472	0.0078	8,666	0.0087
Not Known	5,069	0.0018	36,991	0.0421
Standard Error	2,533	0.0009	21,100	0.0214
Grand Total	2,675,694		876,781	
Sample Size	11,543		5,138	

Table 6.1.15 Estimated Distribution of Persons 13 Years and Older Who Smoke or Use Tobacco in Any Form

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	639,739	0.3318	244,884	0.3795
Standard Error	69,002	0.0180	29,266	0.0234
No	1,287,619	0.6678	400,079	0.6200
Standard Error	85,016	0.0180	23,164	0.0234
Not Known	633	0.0003	254	0.0003
Standard Error	324	0.0001	124	0.0001
Grand Total	1,927,991		645,217	
Sample Size	8,791		3,953	

versus 2.76 million for the 1980 Census. Denver metropolitan statistics by sex can be seen in Tables 6.1.10 and 6.1.11. The proportions are quite comparable; CO study estimates are 47 percent males and 53 percent females compared to 1980 Census statistics of 49 percent males and 51 percent females.

Ages have been grouped for the sake of complying with Census group definitions. These age groups are:

(1) under 18 year of age
(2) between 18 and 64 years of age, and
(3) age 65 and older.

Estimated age group totals and proportions for both sites, compare quite well with Census statistics. Also, the age distributions for the two sites are nearly identical. CO Study estimates for the age groups are presented in Table 6.1.12 and corresponding 1980 Census results are in Table 6.1.13. As can be seen, the percent of individuals under 18 years, between 18 and 64 years, are respectively, about 26 percent and 65 percent (ignoring site and reference source). The comparison for persons 65 years and older is not quite as good. Census data are not available for other items of interest.

The CO Study results for relationships of the respondent to the head of the household screened are categorized in Table 6.1.14. As anticipated, more head of households were screened than any other category, 35 percent and 40 percent for Washington and Denver metropolitan areas.

For the remaining person-level data items, statistical analysis was conducted only for those individuals age 13 and older. Also, estimated totals from data items to follow are far more affected by bias due to item nonresponse than previous data items. The nonresponse is indicated by a reduction in sample size. The point should be emphasized that these proportions are probably reliable, since proportions are not affected as much by nonresponse bias (i.e., if the likelihood of obtaining a response is a random variable). The Washington and Denver study site findings indicate an estimated 33 percent and 38 percent of the respective populations smoke or use tobacco in some form (Table 6.1.15). Between 70 percent and 72 percent of the individuals in these sites work either full or part time (Table 6.1.16). Persons who travel anywhere at least 3 times per week are estimated to be between 82 percent and 84 percent (Table 6.1.17) for the study sites. The majority of persons traveling (anywhere at least 3 times per week) are estimated to take short trips, with most trips actually taking less than 15 minutes (Table 6.1.18). This is true for both sites.

6.1.3 Introduction to Sample Design Results

The sample design for the CO monitoring project incorporated three methodology studies:

(1) The use of telephone directory listings classified by Census geographic variables in association with standard area household sampling techniques to identify sample housing units.

(2) The use of a lead letter mailed to sample subjects stating that they will be called to schedule an appointment for monitoring.

(3) Sampling person-days for monitoring, rather than simply selecting persons and letting each person choose a day to be monitored.

The purpose of the remainder of Section 6.1 is to report the results of these methodological studies.

6.1.4 Use of Geographically Classified Telephone Directory Listings in Association with Standard Area Household Sampling Techniques

As discussed in Section 5.1, the sample design for the CO study was a stratified, three stage design. The EPA purposively selected the metropolitan areas surrounding Washington, D.C., and Denver, Colorado, as the study sites. Area sample segments defined by Census block groups were selected at the first stage of sampling. A computer tape listing the selected block groups was then sent to Donnelley Marketing Corporation. The tape was returned with computerized listings of names, addresses, and telephone numbers for the selected block groups. A sample of listings was then selected for each first stage sampling unit to identify the sample housing units. The screening interviews were conducted by telephone for all sample listings with a telephone number. Since the target population included households other than those with listed telephone numbers, field screening interviews

Table 6.1.16 Estimated Distribution of Persons 13 Years or Older Who Work Either Full or Part Time

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	1,333,061	0.7018	464,960	0.7207
Standard Error	96,555	0.0140	38,133	0.0159
No	561,831	0.2958	179,528	0.2783
Standard Error	42,112	0.0139	13,535	0.0158
Not Known	4,435	0.0023	602	0.0009
Standard Error	1,055	0.0005	258	0.0004
Grand Total	1,899,327		645,090	
Sample Size	8,778		3,951	

Table 6.1.17 Estimated Distribution of Persons 13 Years or Older Who Travel Anywhere at Least 3 Times Per Week

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Yes	1,606,757	0.8406	530,420	0.8221
Standard Error	110,928	0.0085	41,049	0.0130
No	297,010	0.1553	110,533	0.1713
Standard Error	28,404	0.0084	9,833	0.0127
Not Known	7,639	0.0039	4,189	0.0064
Standard Error	2,785	0.0015	2,571	0.0039
Grand Total	1,911,406		645,143	
Sample Size	8,787		3,952	

Table 6.1.18 Estimated Distribution of Amount of Time Spent Traveling One Way at Least 3 Times Per Week for Persons 13 Years or Older

	Washington, DC Metropolitan Area		Denver Metropolitan Area	
	Total	Proportion	Total	Proportion
Less Than 15 Minutes	1,002,041	0.4748	357,480	0.5226
Standard Error	84,829	0.0119	20,647	0.0239
16-30 Minutes	686,847	0.3254	257,484	0.3764
Standard Error	66,360	0.0121	29,920	0.0228
31-45 Minutes	216,547	0.1026	28,013	0.0409
Standard Error	21,000	0.0056	4,445	0.0066
Above 45 Minutes	186,342	0.0883	33,724	0.0493
Standard Error	22,119	0.0067	7,775	0.0097
Not Known	18,380	0.0087	7,314	0.0106
Standard Error	2,015	0.0011	3,433	0.0051
Grand Total	2,110,157		684,014	
Sample Size	9,268		4,152	

were also necessary. A subsample of the listings for which a telephone interview was not possible (see Table 5.1.1) was selected for field screening. Also, a subsample of listings was selected for a missed housing unit (missed HU) check.

The missed HU subsample consisted of 150 listings for Denver and 300 listings for Washington. In each case, the FSUs which had listed 1980 Census occupied housing units 50 percent or more greater in number than those listed by the commercial listings were deliberately oversampled. The missed HU check was implemented by using standard field listing protocol to produce a unique geographic ordering on Census maps for each FSU. Each listing in the missed HU sample was located in the field. The interviewer then proceeded to the next housing unit as identified by the geographic ordering and checked to see if that housing unit was on the commercial list for the FSU. If not, a screening interview was attempted and the check was continued at the next housing unit. When the next housing unit was found to be on the commercial list, the missed HU check was complete. Technically, a screening interview should not have been conducted if the missed HU was on the complete frame of commercial listings and was simply misclassified with regard to Census block group. Interviews were conducted for all missed HUs, regarding them as not simply misclassified, partly to check the completeness of the listings. In most cases, missed HUs occurred in groups of one or two. In one instance, an entire block face of five HUs was missed (See Table 6.1.19). These five missed HUs were regarded as misclassified, and their data were disregarded for analyses and selection of participants for CO monitoring.

The results of the missed housing unit checks for Denver and Washington are summarized in Table 6.1.19. For each study site, approximately two percent of the listings were found to not belong to the FSU, or area segment, to which they had been classified by Donnelley Corporation. Although a unique geographic ordering was not possible for listings outside the assigned area segment, a missed HU check was attempted for these listings. The purpose of this check was mainly to investigate the completeness of the commercial listings. The results in Table 6.1.19 for start addresses outside the segment would seem to

Table 6.1.19 Results of Missed HU Checks

Result	Denver[2] No.	Denver[2] %	Washington[1] No.	Washington[1] %
A. Start Address Inside Area Segment				
1. Completed missed HU check and found no missed HUs	108	72.0	203	67.7
2. Completed missed HU check and found one or more missed HUs	18	12.0[3],[4]	22	7.3
3. Invalid start address	8	5.3	2	0.7
4. Could not locate start address due to incomplete Donnelley listing	0	0.0	1	0.3
5. Could not identify the apartment at which to begin the missed HU check	12	8.0	39	13.0
6. Found one or more missed HUs but not able to complete missed HU check (unable to match names in the Donnelley listings to apartment numbers)	1	0.7	4	1.3
7. Start address and next address were both office complexes; missed HU check was aborted	0	0.0	8	2.7
8. Start address was inside an old age or convalescent home; missed HU check aborted as group quarters were ineligible	0	0.0	16	5.3

continued

Table 6.1.19 (continued)

Result	Denver[2] No.	Denver[2] %	Washington[1] No.	Washington[1] %
B. Start Address Outside Area Segment				
1. Completed missed HU check and found no missed HUs	0	0.0	2	0.7
2. Completed missed HU check and found exactly one missed HU	0	0.0	1	0.3
3. Could not identify apartment at which to begin the missed HU check	1	0.7	0	0.0
4. Aborted missed HU check after traveling one mile, to first corner, or listing nine missed HUs	2	1.3[4]	2	0.7[4]
TOTAL	150	100.0	300	100.0

---

[1] Field work done by Research Triangle Institute.

[2] Field work done by PEDCo Environmental, Inc. under a separate contract.

[3] In one case an entire block face of five HUs was missed. The data for these five HUs was disregarded. These missed HUs were regarded as misclassified.

[4] The data for these missed HUs was disregarded. These missed HUs were regarded as misclassified.

indicate that clusters of HUs, e.g., block faces, tend to be misclassified occassionally and that random misclassification of individual HUs also occurrs.

When the missed HU start address was inside an apartment complex, implementation of the missed HU check was sometimes quite difficult. Table 6.1.19 shows that it was not possible to complete the missed HU check in apartment complexes for about 15 percent of the listings selected for the missed HU check. Since the listings did not generally include apartment numbers, it was necessary to get apartment numbers from mail boxes, apartment managers, or apartment residents. Sometimes these sources proved fruitless. Many of the instances in which a missed HU check could not be begun occurred in restricted-access apartments. Missed HUs seemed to occur more frequently in apartment complexes than in other areas when the check could be implemented. This may be due to the more transient nature of apartment dwellers. Only one missed HU check identified an entire block face (of five HUs) that had been missed by the commercial listings within the selected area segments. The general impression was that the commercial listings provided a reasonably complete listing of housing units.

Most of the listings were found to be correctly classified according to block group. Donnelley Corporation claims that their listings are about 95 percent complete. Our experience is not inconsistent with this claim. However, we found that the undercoverage does not seem to occur at random. Instead, there were small geographic areas for which there were no listings whatsoever. The telephone directories for these areas simply had not been used in compiling the listings. Standard field procedures were used to list all housing units and select clusters of sample housing units for these block groups.

The major problem encountered in using the listings to identify sample housing units was that it was often difficult to locate the housing units corresponding to the sample listings in the field. The addresses generally came from telephone directory listings. Hence, most residents of apartment complexes all had the same address, namely the street address of the apartment complex. This presented some problem for location of the sample housing units. But, more importantly, it made the check for missed housing units very difficult to implement correctly. Because of these problems and other more subtle problems with the operational definition of missed housing units, there seems to be no completely satisfactory way to perform the check for missed housing units for a sample from the commercial listings.

Based upon RTI's cited experience using geographically-classified telephone directory listings, it appears that the best way to use such listings is to select two independent samples. Standard area sampling procedures are used for one sample, and commercial listings are used with the other sample. In particular:

(1) One sample is a standard area sample with sample clusters identified from field listings of all housing units in the selected area segments.

(2) The other sample uses the commercial listings to identify sample clusters in the selected area segments.

It is recommended that the commercial listing sample be used only to generate telephone interviews based upon the telephone directory listings. Using this methodology, the standard area frame sample is used to compensate for the bias resulting from the telephone interviews generated by the commercial listing sample. In order to compensate for this bias, it is necessary to determine whether or not each household in the standard area frame sample is included on the commercial listing frame. This is easily done for commercial listings that come directly from the current telephone directory. A single questionnaire item can determine whether or not the household is served by a residential telephone number that is listed in the current telephone directory. It is not so easy to determine telephone coverage with respect to commercial listings based upon vehicle registrations. Hence, it is recommended that the vehicle registration records be disregarded. See Whitmore, et al. [1983a] for further discussion of these design recommendations.

Use of only the telephone directory listings for the commercial listing sample makes implementation of the dual frame methodology very straightforward. States with and without vehicle registration records in the commercial listings are handled in exactly the same way. For every sample household, one or two questionnaire items can be used to determine the number of residential telephone numbers listed in the current telephone directory for the household. This information is sufficient to facilitate unbiased estimation for linear statistics using either multiple frame multiplicity estimators, such as those discussed by Casady and Sirken [1980], or difference estimators, such as those discussed by Konijn [1973]. The difference estimators may be preferable since they address the bias correction more directly.

The CO study found that there were some area segments with no commercial listings whatsoever. Hence, a determination of whether or not telephone directory listings are available is needed for each area segment in the standard area household sample. If telephone directory listings are not available for some area segments in the standard area household sample, the households in these area segments must be treated for estimation as not represented in the frame of telephone directory listings. Otherwise, all households with a currently listed telephone number are treated as being present on the frame of telephone directory listings.

For monitoring studies, such as the CO study, it is recommended that half of the screening interviews be generated by the standard area frame sample, and half by using the commercial listings sample whenever this procedure is less costly than obtaining the same number of interviews from a standard area frame sample alone. Some savings will be achieved by using the commercial lists instead of lists of housing units produced by field staff to identify sample clusters. The use of telephone interviews instead of field interviews may produce some additional savings. These cost savings will more than compensate for the costs associated with selecting and analyzing two independent samples for studies that require a large number of screening interviews.

This dual frame approach (utilizing two independent samples) could, of course, also be used for a field half-sample and a random-digit-dial (RDD) telephone half-sample. Some advantages of using the geographically-classified telephone directory listings instead of random digit dialing for one-half sample are the following:

(1) Census geographic variables can be used to oversample subpopulations of interest at the first stage.

(2) The proportion of telephone numbers called that are working residential numbers will be much higher for the telephone directory sample.

(3) When field follow-up interviews are necessary, such as for personal monitoring studies, the geographic clustering will reduce subsequent field interview costs.

Of course, there is some loss in precision due to clustering and due to use of the incomplete telephone directory frame. These losses will generally be compensated by decreased cost for the sample survey. Thus, the proposed design is expected to be cost effective for monitoring studies.

6.1.5 Lead Letter Results

The sample design for Washington incorporated a lead letter methodology study, as described in Section 5.1.4. A random sample of 596 of the individuals selected for monitoring was sent a lead letter. The purpose of this lead letter was to inform the sample subject that he or she had been selected for monitoring and that an interviewer would be calling to schedule an appointment for monitoring. The individual was thanked for participating and the importance of the study was stressed. The lead letters appear to have had a positive effect upon response rate. The overall response rate for individuals selected into the Washington sample was about 58 percent, but the response rate for individuals in the lead letter sample was approximately 63 percent. (These response rates are calculated as the number of individuals who agreed to schedule a monitoring appointment divided by the number of individuals selected.) Hence, a person-level response rate of about 65 percent may be possible for future studies of this type using lead letters for all individuals selected for monitoring.

6.1.6 Sampling Person-Days

Individual exposure to carbon monoxide is heavily dependent upon both weather patterns and personal activity patterns, as discussed in Section 5.1.4. Since weather is such an important factor, it was necessary to field as large a sample as possible on each day during the study period. Otherwise, there would be no one monitored on the days with weather patterns producing the highest CO levels. Since personal activity patterns are important, the sample participants could not be allowed complete freedom of choice in selecting a day to be monitored. The sample subjects could introduce a bias by selecting mostly days when they plan to be inactive or stay at home. The strong influences of both weather patterns and personal activity patterns upon CO exposure suggest that a specific day should be randomly selected for each individual to be monitored. However, such a procedure is totally impractical. The response rate would surely be so poor as to invalidate the study if only one day was offered for each sample subject to participate. Hence, the sample for Washington was randomly allocated to non-overlapping three-day interview periods. This procedure had a greater negative impact on the response rate than was at first anticipated. Some sample members indicated that they were willing to participate, but not within the selected time period. These individuals were given one additional opportunity to participate by randomly reallocating them to one new three-day period. A total of 550 individuals were reallocated in this manner for the Washington sample.

The methodology for person-day sampling used for the Washington CO study is somewhat awkward. The reassignment to a new 3-day interview period required constant interaction between field staff and sampling staff during data collection. It also required continual updating of sampling files. Hence, the sampling task was much more expensive than that of a typical sample survey. A better procedure needs to be found for future air monitoring studies. The procedure must control allocation of persons to days and still be somewhat flexible with regard to the allocation to days. A methodology study to explore alternative methods of person-day sampling for studies monitoring personal exposure to airborne pollutants may be needed.

One methodology for person-day sampling could be the following. Suppose six days were randomly selected within the study period for each person selected for monitoring. These could be three consecutive days in one week and the same three days in the next week. Suppose further that priorities from one to six were assigned to the days selected for each person. Each person selected for monitoring could then be told something like the following:

> You recently participated in an EPA-sponsored study by responding to a short questionnaire. You were told that someone might be calling on you to participate in a personal monitoring follow-up study. You have been selected for participation in the follow-up study. Due to the influence on exposure by weather patterns and personal activity patterns, it is necessary to monitor a representative sample of people of each day in the study period. Hence, I have an ordered list of six days that have been selected for you. You are asked to choose the first of these days on which you can possibly participate. Otherwise, your data may be discounted in the analyses and not have as much impact as it would if you had participated on the first available day. Hence, would it be possible for you to participate on (Day 1)?

If the person could not participate on Day 1, the interview would proceed to Day 2, etc. A short reminder that the person needs to choose the first day on which participation is possible might be appropriate between offering Day 1 and Day 2.

Some type of weight adjustment procedure could then be used to compensate for the bias due to self-selection of days. For example, a weight standardization could be performed using a covariance model. This type of procedure could be used to adjust each day's sample to a standardized population, based, for example, on age, race, sex, and occupation. This might require a fairly large sample, e.g., enough to produce more than 25 respondents each day.

6.2 Field Survey Activities

6.2.1 Survey Post-Field Activities

When the field interviewer returned to the respondent's residence at the end of the 24-hour monitoring period, they began a long chain of post-field activities. These activities included editing documents, providing numeric codes for certain alphanumeric fields, entering the data into the computer, and preparing the data for the final step which was the analysis.

As each interviewer retrieved a set of documents from a respondent, the documents were quickly reviewed for completeness and legibility. Any obvious problems were to be addressed and resolved while at the respondent's home. Documents were then returned to the field lab and logged in on the case control card. All materials for each case were maintained separately and material was returned to RTI on a regular basis, transported by the returning members of the field laboratory staff.

When the documents were received at RTI, each case was handled by opening the storage envelope, logging-in on the control card all materials found, and then separating the four documents for the case. All control cards were filed in chronological order. All consent form/-incentive-receipts were batched by wave and hand delivered to the survey task leader for secure storage. The study questionnaires and activity diaries were put into batches (maximum size of 30) for further processing. Batch header sheets (Figure 6.2.1) were created for use in tracing the progress of any batch through the data processing activities.

Batches were first given to editors and coders who were told to review all documents for completeness, to attempt to resolve apparent discrepancies, to attempt to decipher illegible entries, and to code alphanumeric fields, using pre-prepared code specifications. Batches were quality-controlled by the data preparation supervisor who reviewed 100% of the first two batches of each editor/coder, and then 10% of all subsequent batches. Discovery of any systematic errors led to retraining.

After batches were completely edited and coded, they were sent to data entry. Using RTI's mini-computer system, the documents were keyed. A 100% rekey provided complete verification of all data. Any discrepancies between the two keyings caused the keyboard at the data entry station to lock up and required problem resolution before proceeding. Data tapes were prepared on a regular basis with output files checked against hard copy to assure the correctness of the files. Outputs of the mini-computer data entry system were used to create the data tapes, which were then available to the statisticians for use in analysis.

During the first phase of analysis, unusual values, unexpected values, and outliers were identified. These data points were then checked against the hard copy of the data (see Section 5.4). After the problems were resolved, the original hard copy of the data was boxed and stored in data vaults.

Figure 6.2.1

Project 2390

Carbon Monoxide Exposure

BATCH HEADER SHEET

Type of Document		Quantity	Batch Information *	
Study Questionnaire			Batch No.	
Activity Diary			Batched By	
Field Data Sheet			Date Batched	

Action Taken	By Whom	Date
SOC Scan Edit		
Edit and Code		
SOC → Data Entry		
Data Entry		
Data Entry → SRDC		
Stored		

Study Numbers of Enclosed Documents

* Xerox copy of Batch Header Sheet to H. Zelon, 300 Park as soon as created.

6.2.2 Post Data Collection Discussions

After the field data had been collected, two additional interviews took place. One was a validation of a sample of respondents. Several key data points were reviewed and an attempt was made by the supervisor conducting the interview to ascertain data on the performance of the interviewers. All data points checked yielded appropriate responses. Interviewers were given uniformly good comments in terms of being personable, well prepared, and helpful to the respondents. All interviewers were said to have explained the study thoroughly and appropriately. One question was asked about the incentive. Many respondents sampled stated that they would have participated without any compensation, but most were pleased to have received it. Respondents were also asked if carrying the monitor affected their daily routine. The general response was that people maintained their normal schedule of activities.

Each of the field interviewers was also sent a brief questionnaire which collected data on the interviewers experiences during this study. Responses were received and tabulated. In general, the responses received were useful only to provide written documentation of comments already provided by the field staff. Several of the comments from the field staff were useful and are integrated into the study recommendations.

In particular, fifteen responses were received from the field interviewers who were sent the Post-Fieldwork Questionnaire (Appendix L). These responses are representative of those interviewers who worked on the study for the major portion of the effort. The answers to the questions are summarized in the following paragraphs.

Question One asked the interviewers about problems the respondents had understanding the operation of the PEM. The only problems mentioned by the interviewers involved the size and "hassle" of carrying the PEM, confusion with the "on-off" button, and definition of an activity. No one mentioned actual operating problems.

Question Two dealt with the reluctance of some respondents to carry the monitor. Several interviewers reported refusals directly related to the PEM. Some interviewers reported reluctance, later overcome, related to size and potential job conflicts, possibly related to dangerous situations.

Question Three discussed the incentive payment. The comments returned yielded no clear consensus. The only common fact was that less than 40% of the respondents stated that they would have participated if there was no incentive. The remaining comments covered the spectrum of larger, the same, and smaller incentives working equally as well. The single comment that a larger incentive, if big enough, can convert most refusals is a well-known concept but in general is only anecdotally documented.

Question Four involved respondents' difficulties in completing the questionnaire and diary. Problems reported included the difficulty defining and documenting leisure activities, the inconvenience of the diary, some problems with the diary layout, some problems with multipart questions, the tediousness of maintaining the diary, and the reluctance to record activities. In most cases, good interviewers removed difficulties with good explanations and reviews of data requirements.

Question Five asked what additional information could be given to the respondents by phone to reduce fieldwork. Comments included a need for better explanation of the size of the PEM, reduced replication of questions, a need to stress the necessity of the availability of the respondent for two appointments with the interviewer, further explanation of how the respondent was selected, a need to allow respondents to refuse - no oversell by phone, and a stated problem of inadequate screening since some smokers were selected.

Questions Six discussed problems interviewers had in collecting the breath samples. The only problems mentioned were the sample bags leaking, a few concerns over sterility/disposability of the stems, a need to tell respondents about the breath sampling at an earlier point in the study, and a single problem of collecting the sample from a respondent with only one lung.

Question Seven was a branch point to allow those interviewers who had the new H-P unit to continue.

Question Eight discussed respondent reactions to the new monitor. Problems included the existence of too many buttons with poorly defined activities and the lack of reliability of the monitor. One interviewer reported a situation where one family member used the initial PEM and a second member got to use the new version. The new unit was highly "preferred".

Question Nine asked if, after the new model was made more reliable, it could be integrated into this type of study, and if, by thus removing the Activity Diary burden, the response rate would increase. The reactions were that the unit would be useful, but needs to be made smaller with larger buttons. The interviewers felt that the Diary should be maintained as part of the study. It serves as a reminder to the interviewer to be sure the respondent understands the study. The diary is also more easily corrected than the PEM.

6.3 Field Measurements and Quality Assurance

6.3.1 Field Measurement Activities

Field measurement activities took place between June 1, 1982 and April 1, 1983 with the actual acquisition of field data occurring between November 7, 1982 and February 24, 1983. These activities included preparation of the standard procedures for the analysis of breath and ambient CO levels; acquisition, verification, and calibration of field standards and equipment; acquisition of actual field data; and validation, reduction, and preliminary analysis of said data.

6.3.1.1 Personal Exposure Sampling

As mentioned previously, ambient sampling was conducted in seven sampling waves between November 8, 1982 and February 25, 1983. Each wave lasted 2-3 weeks. The target sampling rate varied by wave, with a rate of 10 per day proposed for Wave 1, 15 per day for wave 2, and 20 per day for Waves 3-6. However, because of not being able to schedule enough appointments, sample cancellation, rescheduling at the request of respondents, and COED-1 monitor malfunctions, the rate of successful completion averaged between 8.9 and 12.3 for Waves 1-6.

Since this lower sampling rate lowered the total number of samples acquired to an unacceptable level, sampling Wave 7 was instituted to recover some of those samples lost to scheduling problems, monitor malfunctions, etc. The rate of successful sample completion during this wave was 10.3 per day.

Some statistics for the sampling waves are presented in Table 6.3.1. The percentages for samples completed, cancelled, and lost are based on the number of samples attempted. The percentages for validity code data and for the last 3 rows of the table are based on the numbers of samples completed. It should be noted that an average sample contained approximately 50 time/value pairs. Therefore, the number of mistakes detected represented only a small portion of the total data reviewed (approximately 0.1 percent). Duplicate, colocated samples were collected by lab personnel for the purpose of characterizing monitor precision. The duplicate sampling was discontinued in Waves 2 and 3 due to the shortage of monitors created by the reliability problems coupled with the increased daily sampling rate. Duplicate sampling was diminished during Waves 5 and 6 for the same reasons.

Data in the Table 6.3.1 column marked "Total" represent the status as of the end of the field monitoring phase of the project. At that time, 1051 samples had been attempted in the field (i.e., a field interviewer had left the laboratory with an operating, calibrated monitor). Of those attempted, 814 samples had been completed (i.e., the monitor had been returned to the laboratory in an operating condition and containing apparently valid ambient data). Samples which were cancelled or rescheduled at the request of the respondent accounted for 107 of the 1051 attempted. The remaining 130 samples were lost to monitor malfunctions during the sampling period (i.e., the monitor was returned to the laboratory in a nonfunctioning or malfunctioning condition). During the data validation phase and prior to entry of the data into the study data base, 40 of the 814 completed samples were invalidated for reasons related to the quality of the ambient CO data. Twenty-two samples having a validity code of 4 were invalidated because of differences between pre- and post-sample slopes or intercepts of more than 20 percent or more than 2.5 ppm, respectively. An additional 18 samples having validity codes of 1 - 3 were invalidated due to unreasolvable anomalies in the data. Examples of such anomalies include large blocks of missing time and/or average data within a sample and gross, unre-

Table 6.3.1 Statistics on Ambient Sampling Waves

Sampling Wave	One	Two	Three	Four	Five	Six	Seven	Total
Samples Attempted	123	154	126	192	232	95	129	1051
Samples Completed	111 (90%)	120 (78%)	97 (77%)	134 (70%)	184 (79%)	65 (68%)	103 (80%)	814 (77%)
Samples Cancelled 1/	---	17 (11%)	18 (14%)	21 (11%)	18 (8%)	21 (22%)	12 (9%)	107 (10%)
Samples Lost 2/	12 (10%)	17 (11%)	11 (9%)	37 (19%)	30 (13%)	9 (9%)	14 (11%)	130 (12%)
Validity Code 1 3/	81 (73%) 7/	92 (77%)	69 (71%)	99 (74%)	124 (67%)	44 (68%)	77 (75%)	586 (72%)
Validity Code 2	13 (12%)	18 (15%)	13 (13%)	19 (14%)	33 (18%)	8 (12%)	7 (7%)	111 (14%)
Validity Code 3	9 (8%)	6 (5%)	11 (11%)	7 (5%)	11 (6%)	6 (9%)	4 (4%)	54 (7%)
Validity Code 4	8 (7%)	4 (3%)	4 (4%)	9 (7%)	16 (9%)	7 (11%)	15 (15%)	63 (8%)
Samples Reread 4/	47 (42%)	35 (29%)	12 (12%)	18 (13%)	8 (4%)	9 (14%)	10 (10%)	139 (17%)
Mistakes Detected 5/	---	4	1	1	3	3	2	---
Duplicate Samples 6/	12 (11%)	1 (0.8%)	0 (0%)	14 (10%)	8 (4%)	2 (3%)	14 (14%)	51 (6%)

1/ Samples cancelled or rescheduled at the request of the respondent.

2/ Completed samples for which the data were lost or invalidated due to monitor malfunction.

3/ Codes indicate the relationship between the monitor's pre- and post-sample calibration slopes and intercepts. Code 1 means a successfully completed sample in which the post-sample calibration slope and intercept agreed with the pre-sample slope and intercept to within ± 5% and 1 ppm, respectively. Code 2 indicates a difference of ± 5% to 10% for the slope and of ± 1 to ± 1.5 ppm for the intercept. Code 3 means differences of ± 10% to 15% for the slope and ± 1.5 to ± 2ppm for the intercept. Code 4 slope and intercept differences were greater than ± 15% and 2 ppm.

4/ Samples subjected to duplicate reading of monitor data memory for quality assurance.

5/ Mistakes in individual time or value data detected within a sample during the QC duplicate reading (e.g., for Wave 2, out of 35 samples reread with approximately 50 time/value pairs each, only 4 errors were found).

6/ Duplicate, colocated samples.

7/ Percentages based on completed samples.

solvable differences between activity diary and ambient sample data point times. Invalidation of these 40 samples left 774 valid ambient samples available for inclusion in the data base. As has already been described in Section 5.4.2.1, during the creation of the ambient data file, the remaining 41 samples having a validity code of 4 were invalidated along with 21 other samples eliminated for reasons wholly or partially relating to monitor malfunction. This brought the total number of samples lost due to monitor malfunction to 232. This represented an overall monitor malfunction rate of 22 percent, considerably greater than the 10 percent rate targeted at the beginning of the project. Of these failures, approximately 73 percent were attributable to outright failure while 27 percent were attributable to instability in monitor calibration.

The frequency data listed for the occurrence of each of the four validity codes in Table 6.3.1 indicate that these monitors were generally stable over a 24-28 hour sampling period. Across the entire project, post-sample monitor performance was within ±5 percent of pre-sample performance for the slope of the calibration curve (and within ±1 ppm for the intercept) 72 percent of the time. The slope and intercept were within ±10 percent and ±1.5 ppm, respectively, 86 percent of the time.

6.3.1.2 Analysis of CO Levels in Respondent Breath Samples

Samples of respondent alveolar air (breath samples) were collected throughout the field monitoring phase of the project. Field interviewers collected the samples at the conclusion of the 24-hour ambient sampling period. The samples were analyzed in the field laboratory within 24 hours of collection. Table 6.3.2 presents the results of the breath analysis by ambient sampling wave. Successfully completed samples averaged 5.4 ppm (v/v) with a standard deviation of 5.2 ppm. The geometric mean was 4.4 ppm. Sample values ranged from 1.2 to 54.7 ppm. Successfully completed samples numbered 870. The number of breath samples with valid exposure data was 659.

6.3.1.3 Fixed Site CO Data

During the period of the field study, from November 8, 1982 through February 25, 1983, EPA collected CO data at eleven fixed sites in the Washington, D.C. area. These data were used to classify

Table 6.3.2 Results of Respondent Breath Analyses (ppm)

Sampling Wave	One	Two	Three	Four	Five	Six	Seven	Total
Samples Attempted	125	124	107	134	218	63	121	892
Samples Completed	120	123	103	128	215	63	118	870
Samples Lost [1]	5 (4.0%)[2]	1 (0.8%)	4 (4.5%)	6 (4.5%)	3 (0.1%)	0 (0.0%)	3 (2.5%)	22 (2.5%)
Mean	5.0	5.8	5.6	5.5	5.5	4.1	5.2	5.4
Geometric Mean	4.4	4.5	3.3	4.3	4.6	3.6	4.6	4.4
Standard Deviation	4.1	6.1	5.7	6.1	5.7	2.8	3.7	5.2
Maximum	26.6	43.3	43.1	45.9	54.7	16.9	38.4	54.7
Minimum	1.7	1.5	1.2	1.5	1.6	1.2	1.7	1.2
Room Air Samples[3]	8 (6.7%)	11 (8.9%)	10 (9.7%)	11 (8.6%)	16 (7.4%)	6 (9.5%)	10 (8.5%)	72 (8.3%)
Mean	1.85	2.16	2.31	2.16	2.54	2.52	3.19	2.40
Standard Deviation	0.68	0.60	0.76	0.93	0.84	0.73	1.24	0.90
Range	0.7 - 2.9	1.3 - 3.3	1.2 - 3.9	0.7 - 3.9	1.4 - 4.5	1.7 - 3.5	1.8 - 5.9	0.7 - 5.9

[1] Completed samples lost prior to analysis because of leaking or defective bags.

[2] Based on number of sample attempted.

[3] Analyses of laboratory air performed during the analysis of the breath samples.

days as low CO days and high CO days for later analysis. Table 6.3.3 describes the site characteristics of these monitors and Figure 6.3.1 shows the approximate location of each site on a map of the Washington, D.C. area.

Table 6.3.4 summarizes the results of an analysis of the hourly average values during the period of interest. In this and succeeding tables, the "composite site" data were created by taking the hour-by-hour mean of the hourly values reported by the eleven fixed sites. None of the sites reported hourly average values exceeding the standard of 35 ppm. Table 6.3.5 lists the date and time of the maximum value reported at each site. Eight of the eleven maximum values occurred during either the morning or the evening high traffic periods. Three days (Nov. 8, 1982, Feb. 15, 1983, and Feb. 22, 1983) account for all but one of the maximum values. The maximum value at the composite site was 8.6 ppm and occurred at 18:00 on Feb. 15, 1983.

A file was also created containing the daily maximum 1-hour and 8-hour CO values. Tables 6.3.6 and 6.3.7 summarize the results of an analysis of this data. As indicated in Table 6.3.7, two sites had daily maximum 8-hour values exceeding 9 ppm. Site 090020023I02 reported one exceedance; site 210220001F01 reported five exceedances. None of the sites had daily maximum 8-hour values exceeding 15 ppm.

6.3.2 Problems With Monitors

COED-1 monitors were used throughout the field monitoring phase of this project. GE/HP units were field-evaluated during sampling Wave 7 from February 15 through February 24, 1983. The following problems were noted with each type. It is estimated that approximately 1/4 - 1/3 of the field man-power effort was expended on corrective maintenance and repair activities for the monitors.

6.3.2.1 The COED-1 (GE/Magus) Monitor

A total of 49 COED-1 monitors were employed in the field sampling in Washington. Of these, 6 to 15 monitors were out-of-service on a daily basis for corrective maintenance or repair. This out-of-service rate is attributed to three main causes -- (1) failure of the bias battery mounting system, (2) failure of the nickel-cadmium (Ni-Cd) batteries, and (3) failure of the sample pump.

Table 6.3.3 Site Characteristics of Washington Carbon Monoxide Monitors Operating During Study

Map Code	Location	SAROAD Code	Address	a/ Scale	Probe ht, ft	Distance to road, ft	b/ Vehicles Per Day	Immediate Area Land Use
A	District of Columbia	090020017I01	24th & L. Sts. NW (West End Library)	N	33	83 70 345	12,000 4,500 27,000	Commercial
B		090020023I02	L St. between 20th and 21st Sts., NW	M	11	18 210 250	20,900 13,100 12,800	Street corridor
C		090020031I02	First & C Sts., SW	?	11	50 80	? ?	Office buildings
D	Bladensburg, MD	210220001F01	Educational Media Building	?	13	180	37,000	Residential and light commercial
E	Suitland-Silver Hill, MD	211560001F01	Suitland Parkway (near Bramley Ave.)	N	14	150	19,700	Field near commercial street
F	Alexandria, VA	480080009H01	517 N. St. Asaph St. (near Pendleton)	N	36	40 40	3,900 3,700	Light commercial & residential
G	Arlington, VA	480200020G01	S. 18th & S. Hayes Sts.	N	16	200 200 180	<500 <200 6,000	Commercial and residential
H	Fairfax, VA	481040005G01	10600 Page Avenue	N	12	<100	<200	Office buildings
I	Mt. Vernon, VA	481060018G01	2675 Sherwood Hall Cn.	N	12	190 250 180	17,900 8,250 ?	Light commercial & residential

(continued)

Table 6.3.3 (cont'd)

Map Code	Location	SAROAD Code	Address	a/ Scale	Probe ht, ft	Distance to road, ft	b/ Vehicles Per Day	Immediate Area Land Use
J	McLean, VA	481850001G01	1437 Balls Hill Rd.	N	12	260	31,750	Light commercial & residential
						216	3,189	
						430	10,832	
K	Seven Corners, VA	482870004G01	6100 Arlington Blvd. (roof of Montgomery Ward)	N	30	328	50,000	Strip development near residential
						800	11,658	
						800	1,265	

a/ N = neighborhood
M = micro.

b/ Estimate, accuracy uncertain.

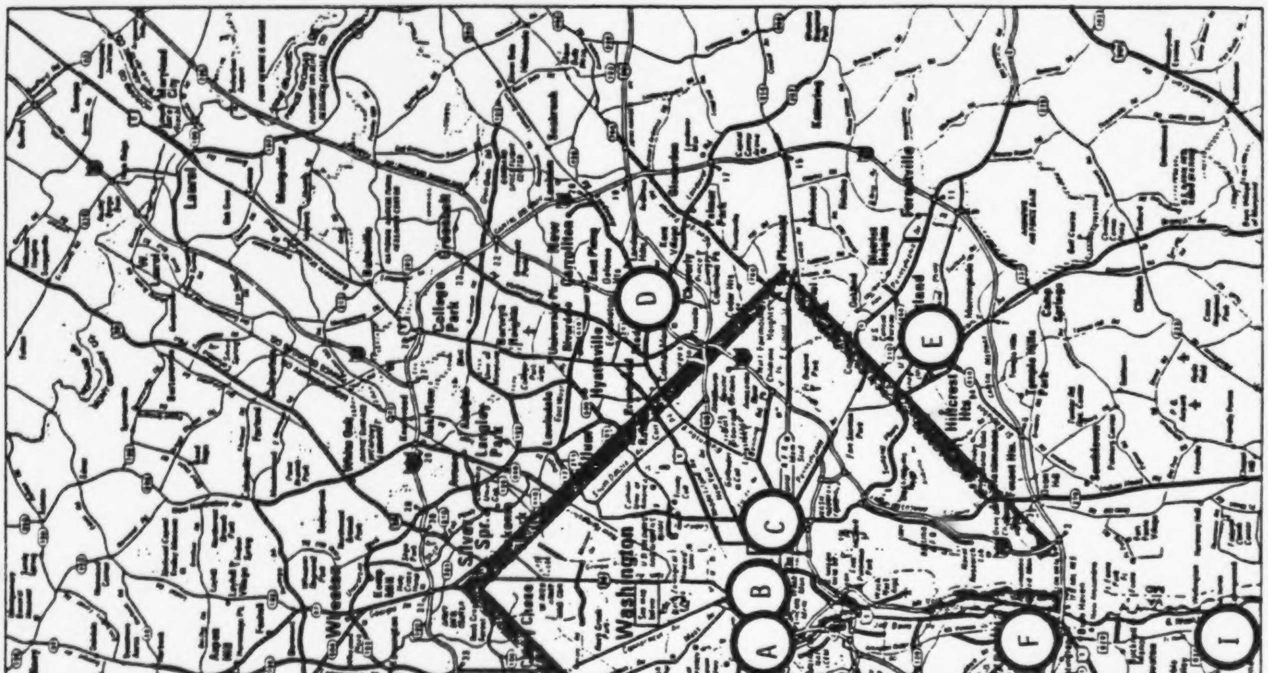

A
B
C
D
E
F
G
H
I
J
K
Washington
Rockville
Bethesda
Chase
Silver Spr.
Wheaton
College Park
Hyattsville
Arlington
Hillcrest Hts.
Annandale

Figure 6.3.1 Locations of Fixed-Site Monitors

Table 6.3.4 Summary Statistics for Hourly Average Carbon Monoxide Values Reported by Washington Monitoring Sites Between November 8, 1982 and February 25, 1983

Map Code	SAROAD Code	Number of hourly Values	Hourly Average Carbon Monoxide Concentration, ppm									
							Percentiles					
			Minimum	Maximum	Mean	Std. Dev.	10	25	50	75	90	98
A	090020017I01	2626	0.1	11.2	1.48	1.22	0.5	0.7	1.2	1.8	2.8	5.4
B	090020023I02	2611	0.1	16.0	2.72	2.22	0.5	1.1	2.1	3.7	5.7	9.0
C	090020031I02	2377	0.1	10.0	1.84	1.14	0.8	1.1	1.6	2.2	3.1	5.4
D	210220001F01	2317	0.0	22.4	1.65	2.22	0.2	0.4	0.9	1.9	4.0	8.9
E	211560001F01	2015	0.0	9.1	1.39	0.97	0.4	0.7	1.2	1.8	2.6	4.1
F	480080009H01[a/]	2563	0.0	14.0	1.38	1.24	0.5	0.5	1.0	1.5	3.0	5.0
G	480200020G01[a/]	2619	0.0	8.5	1.29	1.05	0.5	0.5	1.0	1.5	2.5	5.0
H	481040005G01[a/]	2527	0.0	8.0	1.26	0.94	0.5	1.0	1.0	1.5	2.0	4.5
I	481060018G01[a/]	2608	0.0	17.0	1.78	1.82	0.5	1.0	1.0	2.0	4.0	7.5
J	481850001G01[a/]	2572	0.0	9.5	1.05	1.06	0.0	0.5	0.5	1.5	2.5	4.5
K	482870004G01[a/]	2564	0.0	13.0	0.98	0.91	0.0	0.5	1.0	1.0	2.0	3.5
	Composite	2640	0.2	8.6	1.54	1.09	0.6	0.8	1.2	1.9	2.8	5.0

[a/] Data reported in units of 0.5 ppm.

Table 6.3.5 Date and Time of Maximum Hourly Average Carbon Monoxide Value

Map Code	SAROAD Code	Maximum Hourly Avg., ppm	Date	Time
A	090020017I01	11.2	11-08-82	20:00
B	090020023I02	16.0	02-15-83	19:00
C	090020031I02	10.0	11-08-82	17:00
D	210220001F01	22.4	02-22-83	7:00
E	211560001F01	9.1	02-22-83	7:00
F	480080009H01	14.0	02-15-83	19:00
G	480200020G01	8.5	02-22-83	8:00
H	481040005G01	8.0	02-22-83	8:00
I	481060018G01	17.0	12-08-82	8:00
J	481850001G01	9.5	02-15-83	18:00
K	482870004G01	13.0	11-08-82	9:00

Table 6.3.6 Summary Statistics for Daily Maximum 1-Hour Carbon Monoxide Values Reported by Washington Monitoring Sites Between November 8, 1982 and February 25, 1983

Map Code	SAROAD Code	Number of daily Values	Daily Maximum 1-Hour Carbon Monoxide Concentration, ppm									
							Percentiles					
			Minimum	Maximum	Mean	Std. Dev.	10	25	50	75	90	98
A	090020017I01	110	0.7	11.2	3.56	2.28	1.4	1.8	2.7	4.5	6.9	9.3
B	090020023I02	108	1.5	16.0	6.74	3.30	2.4	4.0	6.6	9.3	11.0	14.1
C	090020031I02	96	0.9	10.0	3.61	1.97	1.8	2.4	3.0	4.3	6.9	9.5
D	210220001F01	93	0.2	22.4	5.12	4.31	1.4	2.4	3.9	6.5	9.2	19.8
E	211560001F01	80	0.4	9.1	2.84	1.66	0.9	1.8	2.3	3.6	5.2	7.6
F	480080009H01[a/]	108	0.5	14.0	3.59	2.34	1.5	1.5	3.0	5.0	7.0	9.0
G	480200020G01[a/]	110	0.5	8.5	2.97	1.86	1.0	1.5	2.5	4.5	5.5	7.5
H	481040005G01[a/]	105	0.5	8.0	2.86	1.78	1.0	1.5	2.5	3.5	5.5	7.0
I	481060018G01[a/]	108	0.5	17.0	4.86	3.20	1.5	2.0	4.5	6.5	9.5	12.0
J	481850001G01[a/]	106	0.5	9.5	2.85	2.00	1.0	1.5	2.5	4.5	5.5	8.0
K	482870004G01[a/]	104	0.5	13.0	2.32	1.79	1.0	1.0	2.0	3.0	4.5	7.5
	Composite	110	0.8	8.6	3.24	1.78	1.4	1.9	2.8	4.1	5.9	7.9

[a/] Data reported in units of 0.5 ppm.

Table 6.3.7 Summary Statistics for Daily Maximum 8-Hour Carbon Monoxide Values Reported by Washington Monitoring Sites Between November 8, 1982 and February 25, 1983

Map Code	SAROAD Code	Number of daily Values	Daily Maximum 8-Hour Carbon Monoxide Concentration, ppm									
							Percentiles					
			Minimum	Maximum	Mean	Std. Dev.	10	25	50	75	90	98
A	090020017I01	110	0.6	7.7	2.35	1.34	1.1	1.3	2.0	2.9	4.2	5.6
B	090020023I02	109	0.8	10.0	4.33	1.98	1.9	2.8	4.4	5.6	7.1	8.2
C	090020031I02	96	0.7	5.9	2.55	1.14	1.4	1.8	2.2	3.1	4.2	5.5
D	210220001F01	89	0.2	12.5	3.12	2.76	0.8	1.4	2.1	4.1	7.2	12.2
E	211560001F01	79	0.3	5.6	1.97	1.05	0.7	1.2	1.9	2.6	3.4	4.3
F	480080009H01[a/]	105	0.5	7.1	2.22	1.42	0.8	1.3	1.8	2.8	4.2	6.4
G	480200020G01[a/]	110	0.5	6.3	2.04	1.27	0.9	1.0	1.6	2.8	3.6	5.2
H	481040005G01[a/]	105	0.5	6.1	1.86	1.05	0.9	1.3	1.6	2.3	2.9	5.0
I	481060018G01[a/]	107	0.6	8.5	3.11	1.98	1.0	1.6	2.3	4.2	6.3	8.2
J	481850001G01[a/]	105	0.4	6.5	1.79	1.21	0.6	0.8	1.5	2.4	3.6	4.9
K	482870004G01[a/]	103	0.3	6.5	1.46	0.86	0.5	0.9	1.3	1.8	2.3	3.6
	Composite	110	0.7	6.4	2.29	1.20	1.1	1.4	1.9	2.7	4.1	5.4

a/ Data reported in units of 0.5 ppm.

The Magus data unit used in the COED-1 monitor was supplied originally with two "hearing aid" type batteries strapped to the circuit boards. These batteries provided bias voltage to various electronic components within the data unit circuitry. The batteries were strapped into their respective circuits utilizing two, spring steel straps -- one soldered to the circuit board and the other screwed to the board. Even before the field monitoring phase was initiated, it became obvious that the battery mounting system was not reliable. If the screws retaining the battery were tightened too greatly, the solder joint(s) on the second strap would break. If the screws were not tightened enough, proper electrical contact between the battery and the circuit could not be maintained. Loss of the bias voltage could produce any of several unpredictable effects. However, the two main effects noted were "lock-up" of the data system logic and rapid discharge of monitor main batteries.

Beginning in November and continuing throughout January, COED-1 units were returned to Magus in California in 6 unit batches for retrofitting of the bias battery system. The battery-and-strap system was replaced with an "active" voltage supply system operating on the main battery package for the data system. This retrofitting eliminated the bias battery problem. However, problems involving a defective batch of integrated circuit chips, erroneous installation of circuit components, erronous wiring of circuit grounds, and the susceptibility of the data unit to static discharge under conditions of low ambient humidity emerged. Magus continued to provide excellent support in monitor repair and problem resolution throughout the field monitoring. However, some of the electric problems with the data unit, particularly the susceptibility to static discharge, were never resolved.

As the number of monitor failures due to the bias battery system and to general electronic defects began to decrease, failures due to the power supply batteries and the sample pump began to increase. This resulted in a relatively constant rate of monitor failures throughout the project. The decrease in the reliability of the Ni-Cd main battery packs was first noted in late December. The packs used to power both the monitoring subsection and the data acquisition subsection began to exhibit increased resistance to accepting a full charge. Additionally, the incidence of failure of single cells within a battery pack increased. This behavior developed dispite a regular program of completely discharging all battery packs once every seven days. Although this problem encompassed the batteries powering both the subsections, the decreased battery performance seemed to be more critical with the monitoring subsection.

The reliability of the GE unit sample pump also decreased during the project. The decrease in performance was caused by several factors including:

(1) wear of the pump bearing surfaces;
(2) loss of resilience in the pump diaphragms and flapper valves;
(3) mechanical failure of the pump diaphragms; and
(4) increased deposition of Purafil® (the prescrubber material) fines in the pump chambers and passages.

The wear of the bearing surfaces, diaphragms, and valves could be attributed to pump aging and could have been corrected by replacement of pumps or diaphragms and valves had replacement parts been available on-site. A question that must be addressed, however, is whether or not such aging is to be expected after a usage period of approximately 900 hours. It may be prudent to seek a pump with a greater life expectancy for use in these monitors.

The increased deposition of Purafil® in the pump could probably be attributed to aging of the prescrubber material and filters. As the active ingredient of the Purafil® (potassium permanganate) was consumed in the prescrubbing process, manganese dioxide was produced as a by-product. Manganese dioxide was released as fines from the scrubber support material by the pulsations inherent in the sample flow stream and by the vibrations produced by physical movement of the monitor. These fines eventually broke through the filters between the prescrubber and the pump and were deposited in the pump chambers and passages, thereby blocking the passages and interfering with the effective operation of the valves. One method of retarding the deposition process, which was used successfully during field sampling, was substitution of a glass wool plug for the two foam rubber pads located at the downstream end of the prescrubber cartridge. However, frequent (once per week) cleaning of the pump and filters coupled with frequent (once every two weeks) changing of the prescrubber material proved to be the only sure way of resolving the deposition problem.

Other, less significant, factors contributing to monitor failure were broken solder joints, disconnection of the data unit from the monitoring unit, switching off of the pump by the respondent, etc. Broken solder joints and other connections were not considered a major problem in these monitors. The occurrance was rare and such a failure was easily repaired on-site. In at least two cases, spot welds holding portions of the monitor's framework together broke. Again, this seemed to be a minor occurrance, however, it was not easily remedied in the field. The accidental switching off of the sample pump by the respondent occurred several times near the beginning of the project. This occurred when the respondent mistook the pump on/off button for the activity button. The problem was solved by making the pump switch inaccessible from outside the monitor's case. This, however, may have contributed to the problems with the monitoring unit's battery life. Defeat of this switch resulted in an operating mode in which the sample pump had to run from the time the monitor left the laboratory on the way to the respondent until the time it was returned approximately one day later. Operating in this mode placed a non-sampling pump load of as many as four hours on the monitor's batteries.

The recommendations for improving the COED-1 monitor are the following:

(1) It is recommended that the electronic problems with the Magus data unit be resolved before this monitor is utilized in another study. The problems which must be address are "lock-up", "mode shift", and susceptatility to static discharge.

(2) It is recommended that alkaline batteries be considered as a substitute for the nickel-cadmiun (Ni-Cd) batteries presently powering the unit. Many of the battery-related monitor failures can be attributed to charging difficulties and other reliability problems with the Ni-Cd batteries. The field staff briefly investigated the feasibility of using alkaline

batteries in these monitors during the project. Our experience indicated that six alkaline batteries would power the data unit for up to seven 24-hour sampling periods before replacement was necessary. Additionally, 4 alkaline batteries adequately powered the GE-CO unit for up to four 24-hour periods.

(3) It is recommended that the availability of a more durable sample pump, which is still compatible with monitor specifications, be researched. Field experience demonstrated that the service life of the currently utilized pump may be as low as 900 hours.

(4) It is recommended that the configuration of the sample flow path be modified such that the flow through the prescrubber is up with respect to gravity. If this is not possible, the scrubber should be oriented in a horizontal configuration. This change will eliminate or, at least, minimize the deposition of prescrubber material fines in the pump. An efficient filter between the prescrubber cartridge and the pump may resolve the problem satisfactorily. However, such a filter must be easily replaceable because experience has shown that it will be contaminated quickly.

(5) It is recommended that the unit be equipped with a sample pump on/off switch which is inaccessible to the respondent, but available to the interviewer. Availability of such a switch will allow the sample pump to be turned off during periods other than those of actual sampling. This will, in turn, reduce the load on the monitoring unit batteries.

(6) It is recommended that the electrical connection to the sample pump be modified to facilitate removal and replacement of the pump. The connection is presently made by soldering a piece of printed circuit tape to the pump motor terminals. In light of the requirement for frequent pump removal (for cleaning, repair, or replacement) discovered during this project, the present system is cumbersome and time-consuming.

6.3.2.2 The GE/HP Monitor

During the seventh sampling wave, the field team evaluated 10 units of a new version of the CO monitor. This new version utilized the GE CO-3 CO monitor as the COED-1 had. However, the Magus data unit had been replaced by an HP-41CV programmable calculator and an HP-IL interface loop and converter acting as the data acquisition unit.

Several problems, with both the HP-41C program and the monitor, itself, prevented the acquisition of valid field data from these monitors. The unit was designed and assembled by Rockwell, who also designed the original program for the HP-41CV calculator. This original program, while performing the data acquisition and monitor controlling tasks admirably, performed numerous data analysis tasks in the routine acquisition loops. Because of these tasks, the logic in the acquisition loop required approximately 8 seconds to execute. Since the loop was programmed to execute every 10 seconds, only 2 seconds in ten were available for respondent activity initiation. This length of time was deemed inadequate by both EPA and RTI. Therefore, the program was completely rewritten by EPA personnel. While the rewrite remedied the loop timing problem, it also deleted certain essential logic controlling monitor power-up and power-down. Without this logic, the monitor remained 100 percent powered-up at all times resulting in depletion of the monitor's batteries after only 8 hours. Additionally, the rewritten logic did not handle seldom arising situations such as a respondent initiating an activity exactly on the hour. The program was written for a third time by RTI field personnel just prior to the initiation of sampling Wave 7. The acquisition loop logic was shortened and the loop was programmed to execute once every 15 seconds. The final configuration allowed for from 8 to 12 seconds per loop for activity initiation depending on the characteristics of the individual HP microprocessors. The power-up/power-down logic was refined and included provisions for putting the monitor "to sleep" (i.e., putting the monitor in program controlled standby mode for battery conservation) whenever the sample pump was turned off. Logic was also included to shut down the entire data system if main battery failure occurred. This provision was designed to protect any previously accumulated data from being lost due to the battery failure. This program performed the acquisition and control tasks as well as the original program, while holding the acquisition loop execution time to a minimum.

Unfortunately, the monitor problems which developed following the preparation of the program prevented the acquisition of any significant amount of ambient data. Rockwell provided EPA with a main battery charging rig to charge the lead-acid gel cells used by these monitors. Field personnel began charging batteries immediately after the arrival of the monitor on-site in preparation for the initiation of sampling. However, the charging rig was defective, producing an excessive charging rate which destroyed the charger and partially damaged most of the cells. The damage prevented the batteries from accepting a full charge and, thus, substantially reduced the capacity of the cell. The reduced capacity proved insufficient to operate the monitors for the required 24-28 hour sampling period.

The battery charging problem was discussed with Rockwell personnel who suggested several possible field repairs to keep the monitors in operation. One repair, not available to the field team, was the replacement of the damaged batteries. The battery manufacturer could not supply replacements rapidly enough to be of any use to the project. The EPA Project Officer was informed of the problems and repair options were discussed. It was decided to attempt reasonable field repairs with the objective of obtaining, at least, some performance data on the monitors. A new battery charging rig was assembled in an effort to adequately charge any batteries which were not damaged. Discharge curve experiments were undertaken to determine the extent of battery damage. These efforts did allow sampling to begin with the new monitors. However, several new problems developed during the sampling periods which usually resulted in the loss of most or all of the sample data. The problems included:

(1) refusal of a monitor to "wake up" when the intereviewers started the sample pump,

(2) destruction of IC chip U16 resulting in loss of sample pump speed control, and

(3) spontaneous "going to sleep" by the monitor while the sample pump continued to run.

When the same monitors that had demonstrated the above described failures were operated in the laboratory on a maintenance charger, valid 24-hour samples were obtained without difficulty. These results indicated that the problems were battery related rather than monitor design or program design related. Sampling attempts continued throughout the 10 days of Wave 7 at a rate of 4-5 per day. However, only one complete, valid sample was obtained. Three additional 1/2 - 3/4 complete samples were obtained.

Recommendations for improving the GE/HP monitor are:

(1) It is recommended that the electronic design of this monitor be carefully reexamined and modified as necessary to eliminate the various logic faults experienced during this project.

(2) It is recommended that the compatibility of the lead-acid gel cell batteries with this unit be examined carefully. There are indications that the batteries may not be capable of powering the current design for the 28-32 hours generally required.

(3) It is recommended that, after the battery capacity question is settled, clear and complete instructions for charging said batteries be written and that charger/charging circuits of appropriate capacity be assembled and supplied to future users.

(4) It is recommended that the packaging of the unit be redesigned. The two-component package with its interconnecting wiring is cumbersome and represents a reliability problem due to broken and disconnected leads.

(5) It is recommended that, if the batteries are to be removed from the monitor for charging, they should be made more easily accessible and easier to remove. Additionally, the battery connections should be polarized to prevent accidental reversal of polarity.

(6) It is recommended that these monitors be thoroughly evaluated, both in the laboratory and in the field, before being employed in another sampling project.

6.3.3 Quality Assurance Activities

6.3.3.1 Quality Assurance Project Plan

The Quality Assurance Project Plan was prepared during the months of June and July, 1982. A copy of the approved plan is contained in Appendix I.

6.3.3.2 External (EPA-Conducted) QA Systems Audits

In November/December 1982 and in January 1983, EPA conducted external QA systems audits of the field laboratory. These audits examined the opacity system and determined the performance of the PEMs and the breath analyses. They also examined the general operation, record keeping, data reporting, data custody, and QC activities of the laboratory. Both audits found that the analyses were within the projected ±10 percent tolerances, that the COED-1 monitors did not suffer sensitivity decreases with time generally, and that the output from the monitors exhibited excellent linearity from zero to full range.

6.3.3.3 Internal (RTI-Conducted) QC Audit

On January 20 an internal quality control systems audit of the field laboratory was performed by the RTI QA coordinator for the project. The audit revealed that the field operation was being conducted in accordance with the project QA plan and good QA practice. However, one deficiency was noted. Duplicates of the field sampling data sheets were not being maintained either in the field laboratory or at RTI. This deficiency was remedied immediately by initiating a program of data sheet duplication in the field laboratory before the sheets were transferred to RTI. This was deemed appropriate even though all data sheets were being hand-carried from the laboratory to RTI. Once the sheets reached RTI, they were duplicated for a second time and the originals stored in a safe file in sealed packages. Additionally, all data that had been transferred to RTI prior to the audit was immediately duplicated and the originals were placed in the safe files.

6.3.3.4 Multipoint Calibrations to Assess Monitor Linearity

In early January (between Waves 3 and 4) and again in early March (following Wave 7), all COED-1 monitors currently in operating condition were subjected to a multipoint calibration to assess response linearity. Prior to delivering any monitors to RTI, EPA had completed such a calibration and reported that all monitors displayed good linearity. These calibrations were based on monitor response to atmospheres defining six upscale concentrations (3.5 - 200 ppm) of carbon monoxide as well as monitor responses to a zero concentration matrix. The data from the calibrations were reduced according to the technique of least-squares linear regression using the atmosphere concentrations as the independent variable and monitor responses as the dependent variable. Within the two calibrations, a total of 78 monitors were calibrated. The slopes of the regression lines ranged from 0.64 to 1.20 with an average of 0.98 and a standard deviation of 0.10; intercepts ranged from 0.14 to 4.08 with a mean and standard deviation of 1.63 and 0.93, respectively. No zero or less-than-zero values were expected for the intercepts of these lines due to the practice of setting the monitor zero level at a nominal value of 1.0 ppm. This value was chosen to avoid the likelihood of negative responses to near-zero concentration levels due to monitor drift. This was necessary because the Magus data acquisition system interpreted all incoming negative data as the absolute of the data. The coefficient of determination (r^2) was computed to describe the linear relationship between the calibration atmospheres and the monitor responses. It ranged from 0.9993 to 0.9999 with an average of 0.9997. This indicated that the linearity of response for all analyzers was well within acceptable limits.

6.3.3.5 Monitor Stability Over the Course of the Study

In order to characterize the stability/variability of the monitors with time in general, a series of five control charts was maintained for each of the 49 COED-1 monitors used during the course of the study. Another objective of the control chart series was that they were useful as a tool for predicting when degrading monitor performance would become unacceptable. An example of each of these charts is presented in Figures 6.3.2 through 6.3.4. Figure 6.3.2 depicts the variability in the differences between pre- and post-calibration zero and span response over the course of the study. The event numbers on the abscissae refers to the sequential number of times that the monitor was selected for assignment to a sample. Event numbers with missing

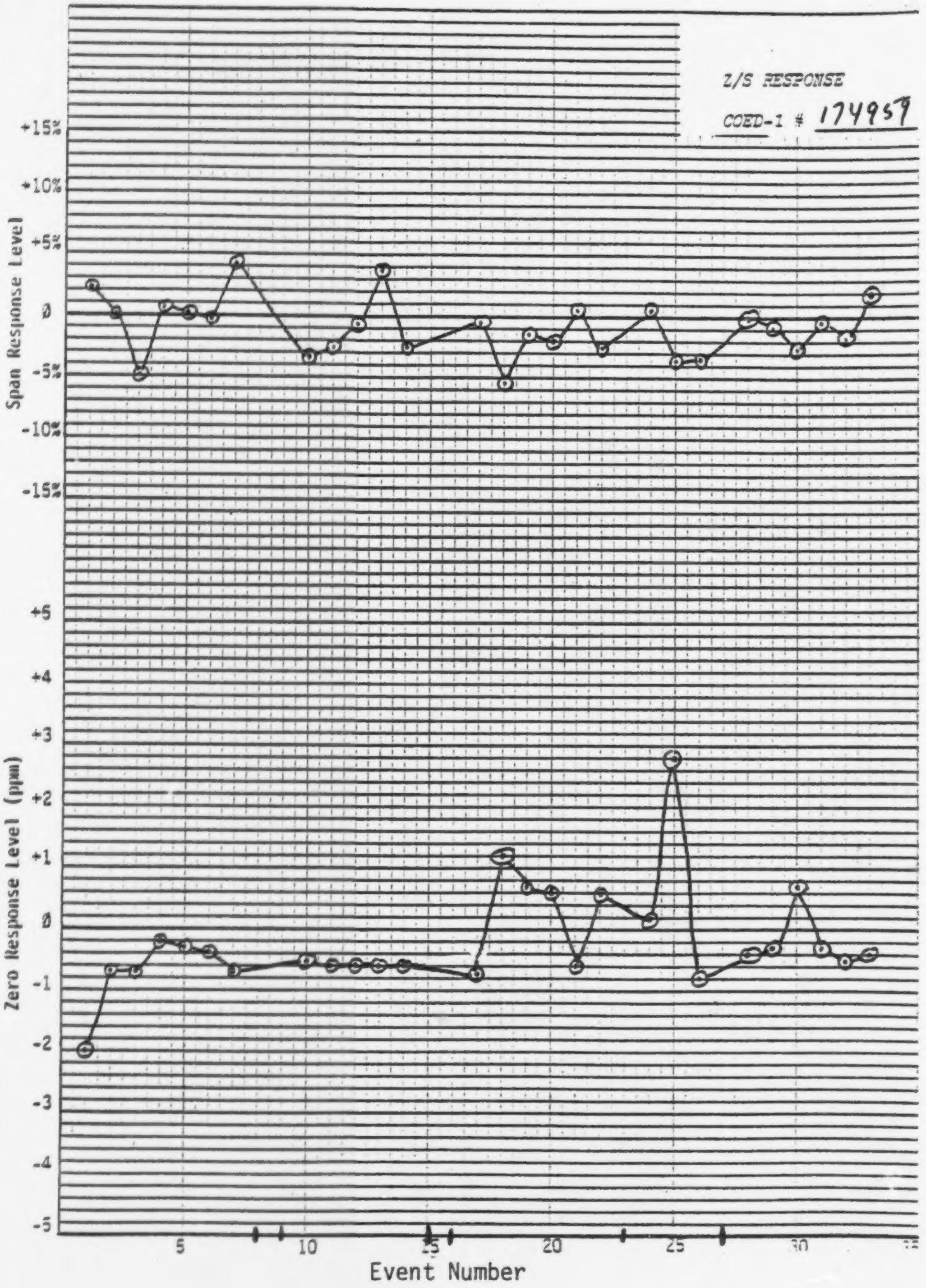


Figure 6.3.2. Response Levels

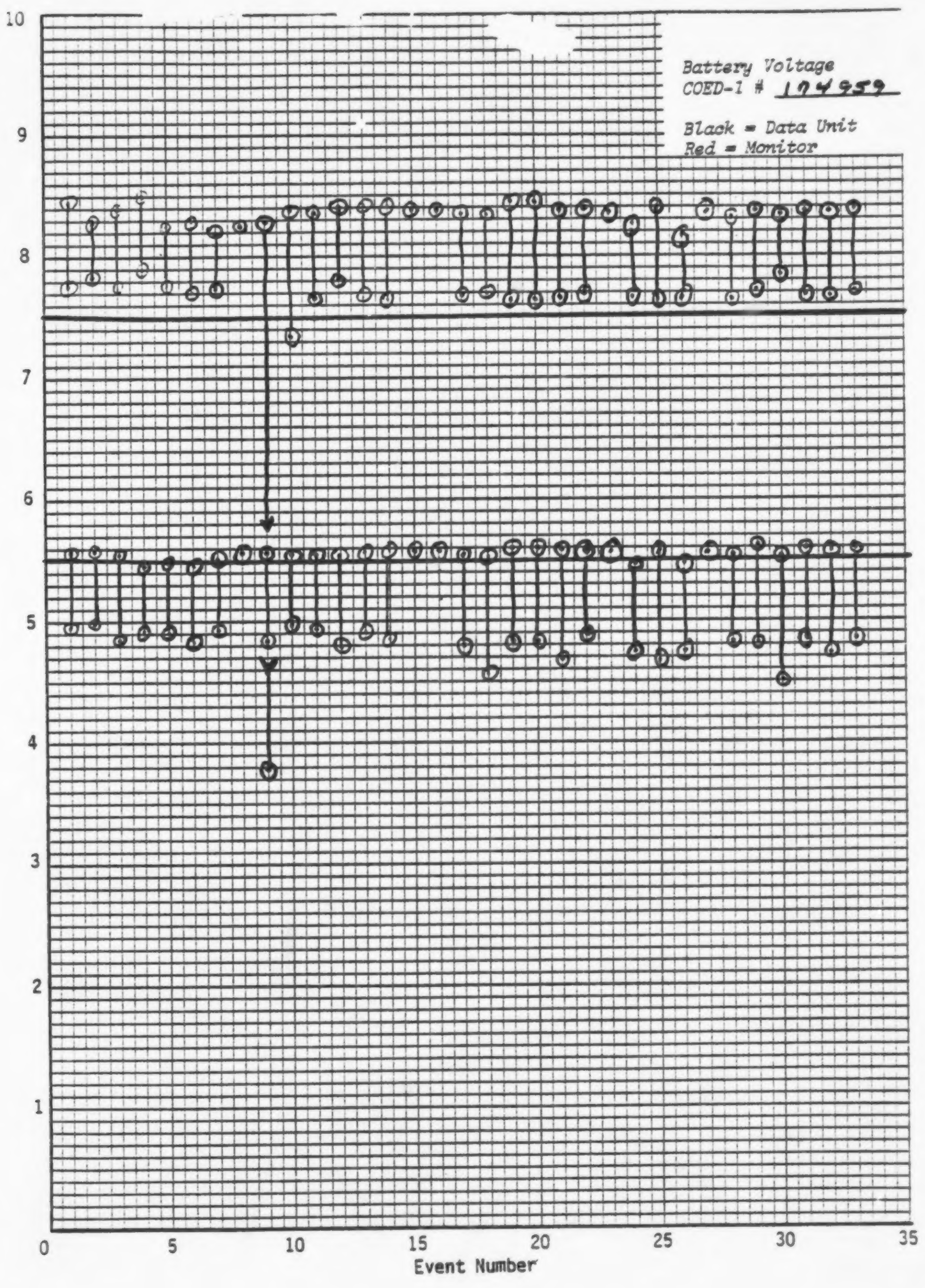


Figure 6.3.3. Monitor Battery Voltages (volts)

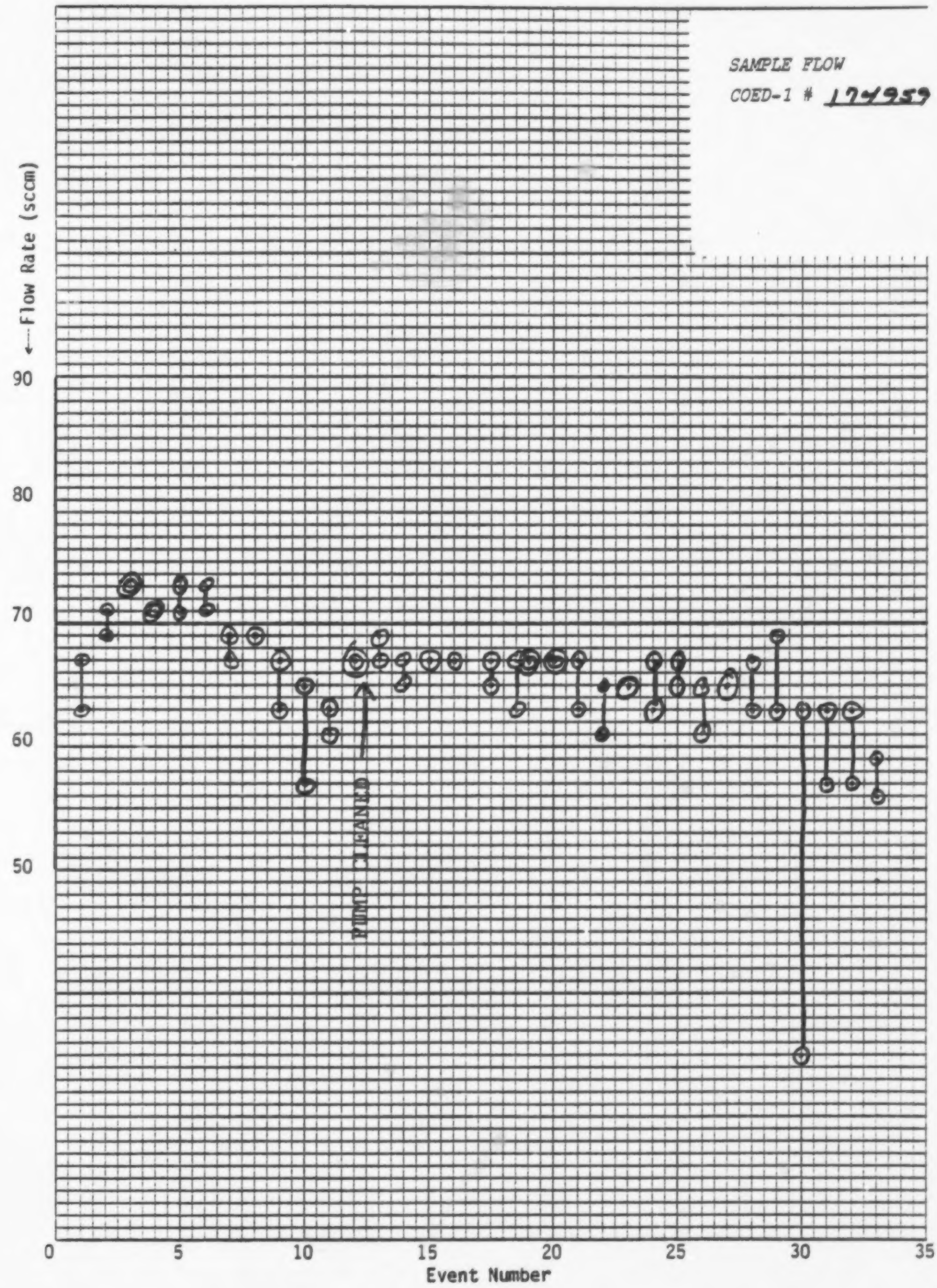


Figure 6.3.4. Flow Rate

values indicate times that the monitor was assigned to a sample and was returned to the laboratory in a nonfunctioning or malfunctioning condition. Figure 6.3.3 displays pre- and post-sample voltage levels of the monitors main battery packs. The upper sequence of points at about eight volts refers to the data unit battery pack; the lower sequence refers to the CO analyzer battery pack. In point pairs joined by vertical lines, the upper point is the pre-sample voltage; the lower point is the post-sample voltage. Figure 6.3.4 depicts the variability in sample flow rate. Again, in point pairs joined by a vertical line, the upper point represents the pre-sample flow rate. Points within double circles represent samples where the post-sample flow was the same as the pre-sample flow. In some cases the flow rate actually was higher after the sample than before it, although no such cases are depicted here.

6.3.3.6 Assessment of Measurement Precision and Accuracy

During the field monitoring phase of the project, certain procedures were undertaken to assess the precision and, where possible, the accuracy of the measurement process for both breath and ambient CO levels.

Precision of PEM Values. The assessment of the precision of the ambient measurement was performed by having a member of the project field staff carry two or more randomly assigned COED-1 monitors for a 24-hour period. The staff member was instructed to carry the monitors with him, wherever he went, throughout his daily activities. Thus, the monitors were exposed to typical sampling conditions of changing temperature, humidity, elevation, etc. as well as to the vibrations and physical shocks inherent in transporting the instruments. Each instrument was calibrated before and after the sampling period just as it would have been had it been assigned to a regular sample. The field staff member made no attempt to define activities during the sample, nor did he keep an activity diary. If he did activate the activity button, he was instructed to do so on a random basis and to activate the buttons for all monitors assigned to him simultaneously. Twenty-eight 24-hour samples were obtained. After the sampling period, the acquired data were off-loaded from each monitor separately following the same procedures used for routine samples. The data were transferred to the study data base, validated, and analyzed for variations among replicate samples. The description and results of this analysis are presented in Section 6.4.4 of this report.

Accuracy of PEM Values. The accuracy of the ambient measurement was evaluated in two ways during the project -- (1) EPA-conducted, independent performance audits and (2) colocation of COED-1 monitors with EPA-designated reference analyzers operated by the District of Columbia air pollution agency. As has been previously mentioned, two, independent, EPA audits found that the ambient analyses were within the projected ±10 percent tolerances. Accuracy was also assessed by colocation of COED-1 monitors with District of Columbia fixed site monitors. Eleven, 22-hour samples were acquired in this way from two different DC fixed site stations -- the West End Library site (SAROAD NO 090020017I01) and the C&P Telephone Building site (SAROAD NO 090020023I02).

The COED-1 monitors which were randomly assigned to these colocated samples, were calibrated, maintained, and utilized as they would have been for routine samples. At the conclusion of a sampling period, the acquired data were off-loaded from the colocated monitors as with regular, ambient samples. The COED-1 data were compared with the fixed site data by obtaining the difference produced when the fixed site average for a particular hour at a particular site was subtracted from the COED-1 datum for the same hour and site. The mean of the 242 differences so obtained was -0.515 ± 0.0557 ppm at the 95 percent confidence level (i.e., the fixed site was, on the average, larger). The differences ranged from -1.72 to +0.33 ppm; concentrations observed at the fixed sites during the comparison ranged from 0.10 to 8.60 ppm. The distribution of the differences obtained during the comparison is presented in Figure 6.3.5. The figure clearly indicates that in general the diff(PEM-FSM) was negative.

The hourly averages determined by the COED-1 monitors were regressed against the corresponding averages obtained from the fixed site monitors. The regression analysis yielded a slope, intercept, and coefficient of determination of 0.947 ± 0.034 ppm, -0.411 ± 0.084 ppm, and 0.927, respectively. A plot of the COED-1 averages versus the fixed

Figure 6.3.5. Washington, D.C. Personal CO Exposure Project PEM vs. Fixed Site Monitor (FSM) Comparison

```
                                  Frequency Bar Chart

Midpoint                                                                    Cum.              Cum.
  Diff    Difference of PEM from FSM in PPM (PEM-FSM)                 Freq  Freq  Percent   Percent

-1.6000   !**********                                                    5     5     2.07      2.07
-1.5000   !********************                                         10    15     4.13      6.20
-1.4000   !                                                              0    15     0.00      6.20
-1.3000   !****                                                          2    17     0.83      7.02
-1.2000   !**********                                                    5    22     2.07      9.09
-1.1000   !******                                                        3    25     1.24     10.33
-1.0000   !********************                                         10    35     4.13     14.46
-0.9000   !************************                                     12    47     4.96     19.42
-0.8000   !************************************                         18    65     7.44     26.86
-0.7000   !************************************************             24    89     9.92     36.78
-0.6000   !************************************************             24   113     9.92     46.69
-0.5000   !******************************************                   21   134     8.68     55.37
-0.4000   !**********************************                           17   151     7.02     62.40
-0.3000   !**************************************************           25   176    10.33     72.73
-0.2000   !********************************************                 22   198     9.09     81.82
-0.1000   !****************************                                 14   212     5.79     87.60
 0.0000   !************                                                  6   218     2.48     90.08
 0.1000   !**********************                                       11   229     4.55     94.63
 0.2000   !****************                                              8   237     3.31     97.93
 0.3000   !**********                                                    5   242     2.07    100.00
          ----+---+---+---+---+---+---+---+---+---+---+---+--
              2   4   6   8  10  12  14  16  18  20  22  24

                               Frequency
```

site averages is presented in Figure 6.3.6. The comparison data were examined by site to determine if the observed differences were site-dependent. No significant difference between the two sites was noted (Library site mean: -0.528 ± 0.058 ppm; C&P site mean: -0.499 ± 0.101 ppm; t(240) = 0.50, not significant). Plots and frequency distributions of the comparison data by site are presented in Appendix M.

Examination of Figure 6.3.6 revealed that a substantial number of zero responses were obtained from the COED-1 units when fixed-site-determined concentrations ranged from 0.1 to 1.4 ppm. Further examination of the comparison data on a sample-by-sample, COED-1 monitor-by-monitor basis indicated that the minimum sensitivity of the COED-1 monitors varied on a monitor-by-monitor basis and ranged from approximately 0.2 ppm to approximately 2.0 ppm. Figures 6.3.7 and 6.3.8 present examples of this variability in minimum sensitivity for two representative COED-1 monitors. Plots of COED-1-determined concentration versus fixed site monitor-determined concentration for the remaining nine samples are presented in Appendix M.

The comparison data were examined at or above fixed site/PEM concentrations of 1.0 ppm to determine whether or not the poor sensitivity near zero concentration had unduly influenced the mean difference between the COED-1 and fixed site monitors. No significant difference was noted (mean difference for data above 1.0 ppm: -0.472 ± 0.091 ppm). A plot and a frequency distribution of the data above 1.0 ppm are presented in Appendix M.

The relationship between the PEM-determined concentrations at or above 1.0 ppm and fixed site-determined concentrations at or above 1.0 ppm was examined another way utilizing the statistic:

$$((PEM-FSM) / FSM) * 100,$$

where: PEM = the PEM-determined concentration (ppm), and

FSM = the fixed site monitor-determined concentration (ppm).

This statistic produces a concentration-normalized difference expressed as a percentage of the fixed site concentration at which the difference was observed. The mean normalized difference so obtained was -15.0 ± 2.76 percent at the 95 percent confidence level. The interval into which the "next observed value" of this statistic is expected to fall 95

Figure 6.3.6

WASHINGTON, DC PERSONAL CO EXPOSURE PROJECT
PEM VS FIXED SITE MONITOR (FSM) COMPARISON

PLOT OF PEMCONC*FSM   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

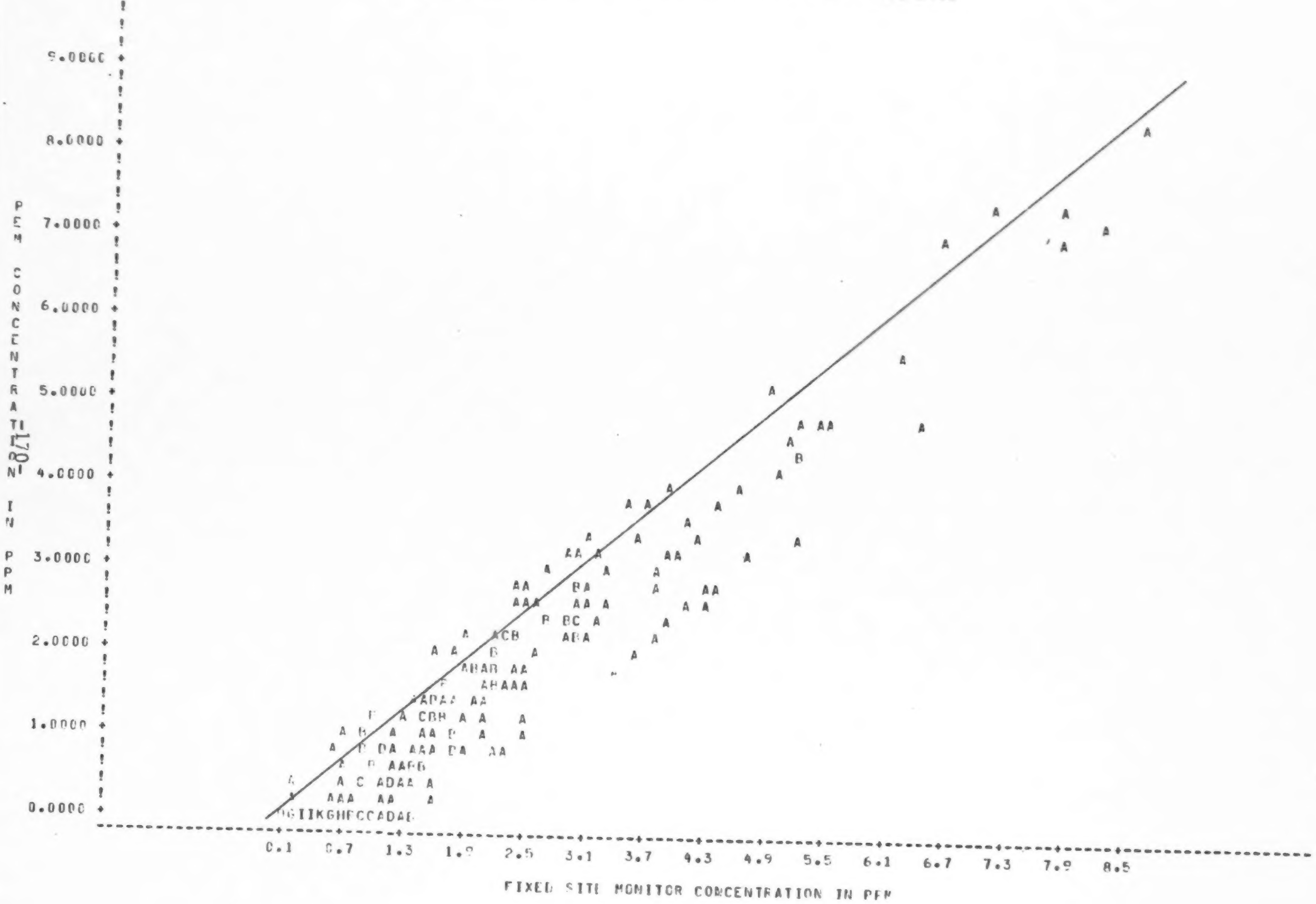


Figure 6.3.7

WASHINGTON, DC PERSONAL CO EXPOSURE PROJECT
PEM VS FIXED SITE MONITOR (FSM) COMPARISON
FID=7000417

PLOT OF PEMCONC*FSM   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

(PEM set to .05 if PEM reading ≤ .05)

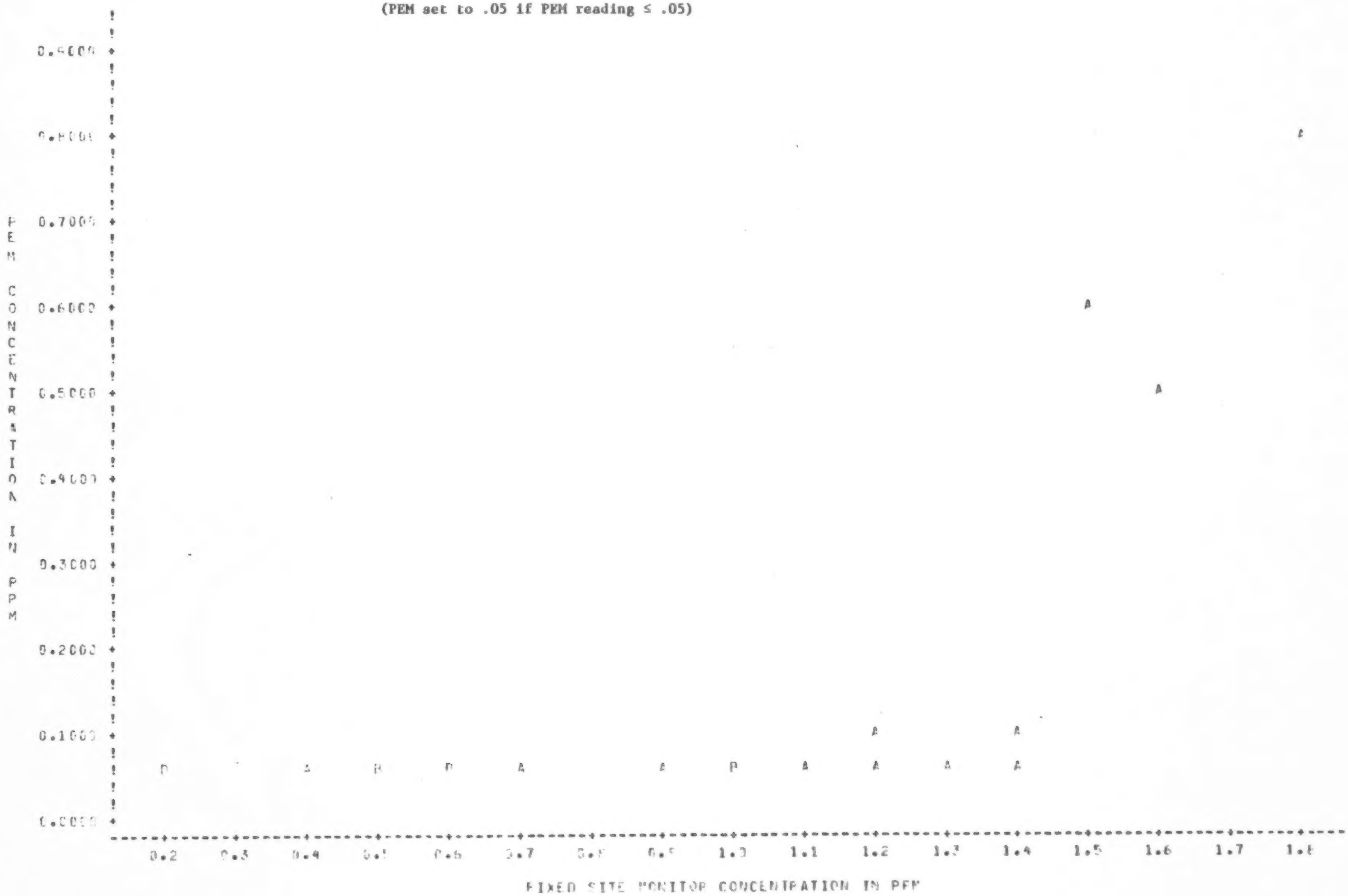
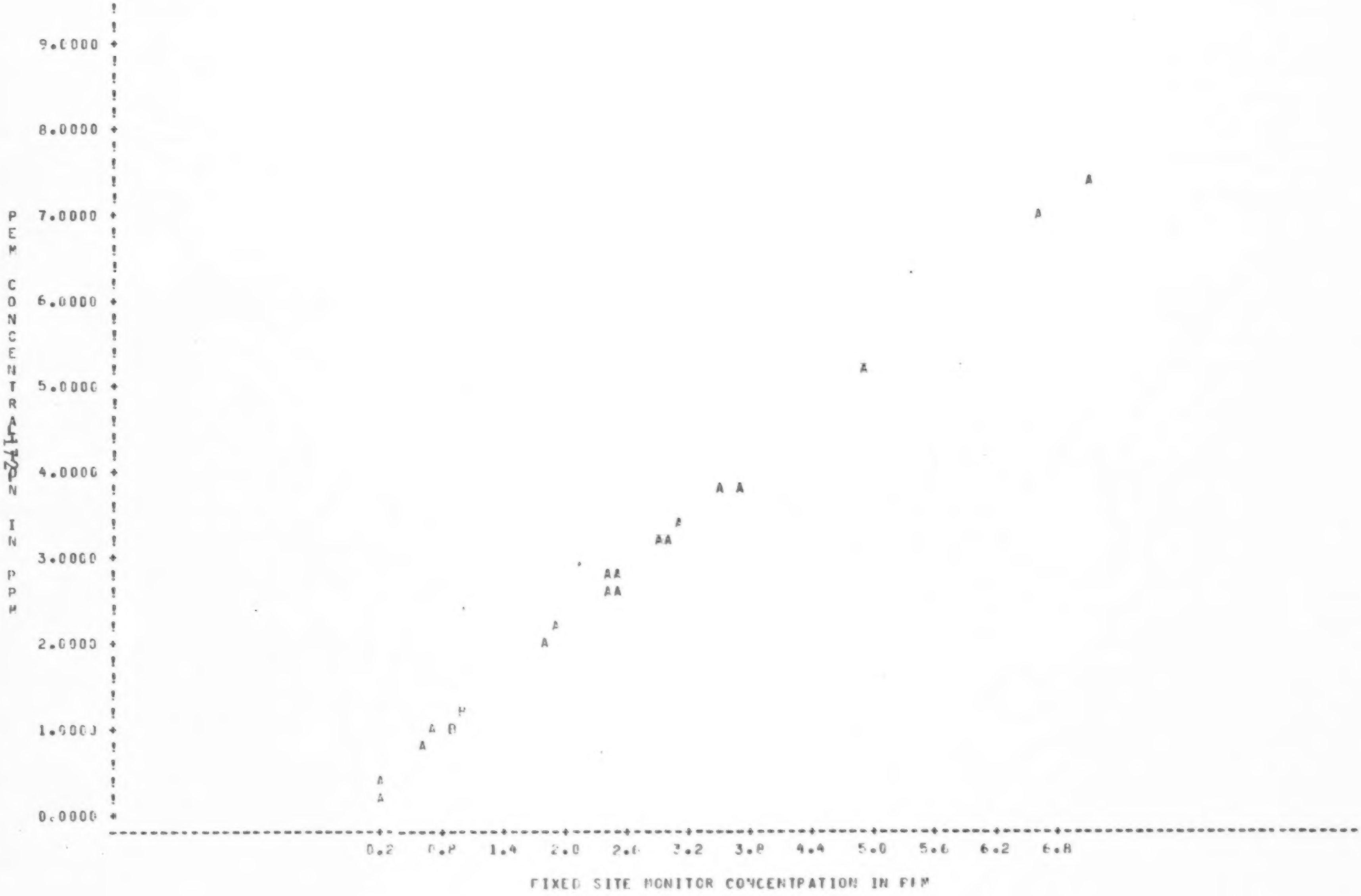


Figure 6.3.8

WASHINGTON, DC PERSONAL CO EXPOSURE PROJECT
PEM VS FIXED SITE MONITOR (FSM) COMPARISON
PID=7000524

PLOT OF PEMCONC*FSM   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



percent of the time (i.e., the 95 percent prediction limit) is -15.0 ± 30.2 percent. A frequency distribution for this statistic over this comparison is presented in Figure 6.3.9.

Three conclusions can be drawn from the analysis of the comparison data from COED-1 and fixed site monitors. First, there appears to be a consistent -0.5 ppm bias in the COED-1 data with respect to the fixed site data. This bias is neither site-dependent nor absolute concentration dependent within the constraints of this analysis. Second, this analysis indicates that PEM-determined concentrations will be within ±30 percent of the fixed site monitor-determined concentrations 95 percent of the time, once any consistant bias between the methods (-15 percent in this analysis) is taken into consideration. Finally, the COED-1 monitors appear to exhibit varying minimum detectable sensitivities that vary from monitor-to-monitor and range from 0.2 to 2.0 ppm.

Precision of Breath Values. The data derived to assess the precision of the respondent breath analyses were based on duplicate samples obtained from respondents by having them inflate two separate breath sample bags. The mean difference between duplicates analyzed during the project was 0.11 ± 0.13 ppm at the 95 percent confidence level. Results of paired difference tests performed on the duplicate analysis data at the 95 percent confidence level indicated that the mean difference was not statistically different from zero. Additional statistical tests performed on the results of analysis of laboratory and field blank breath samples indicated that the blanks were not significantly different from zero nor were they significantly different from each other. Results of analyses of control samples at levels of 3.5, 10, and 40 ppm indicated that the controls generally did not vary from their nominal value a statistically significant amount. When the variation became statistically significant, it was due to small standard deviations and was not of practical significance. Additionally, field and laboratory control analyses were not significantly different from each other.

Accuracy of Breath Values. A straightforward assessment of the accuracy of the breath analyses procedure was not possible since there was no "reference value" with which to compare them. However, results of EPA-conducted audits of the breath analysis procedure indicated

Figure 6.3.9

```
                      WASHINGTON, DC PERSONAL CO EXPOSURE PROJECT
                        PEM VS FIXED SITE MONITOR (FSM) COMPARISON
                           FOR CONCENTRATION DATA >= 1.0 PPM

                                   FREQUENCY BAR CHART
MIDPOINT                 1/
NORMDIFF    DIFF NORMALIZED FOR FSM CONCENTRATION                                     FREQ   CUM.  PERCENT      CUM.
                                                                                             FREQ             PERCENT
           !
  -0.5600  !*****                                                                         1      1     0.84      0.84
           !
  -0.5200  !                                                                              0      1     0.00      0.84
           !
  -0.4800  !**********                                                                    2      3     1.68      2.52
           !
  -0.4400  !***************                                                               3      6     2.52      5.04
           !
  -0.4000  !***************                                                               3      9     2.52      7.56
           !
  -0.3600  !*************************                                                     5     14     4.20     11.76
           !
  -0.3200  !******************************                                                6     20     5.04     16.81
           !
  -0.2800  !****************************************                                      8     28     6.72     23.53
           !
  -0.2400  !****************************************                                      8     36     6.72     30.25
           !
  -0.2000  !**********************************************************************       14     50    11.76     42.02
           !
  -0.1600  !*******************************************************                      11     61     9.24     51.26
           !
  -0.1200  !***************************************************************************  15     76    12.61     63.87
           !
  -0.0800  !*******************************************************                      11     87     9.24     73.11
           !
  -0.0400  !****************************************                                      8     95     6.72     79.83
           !
   0.0000  !*************************                                                     5    100     4.20     84.03
           !
   0.0400  !***********************************                                           7    107     5.88     89.92
           !
   0.0800  !******************************                                                6    113     5.04     94.96
           !
   0.1200  !*************************                                                     5    118     4.20     99.16
           !
   0.1600  !                                                                              0    118     0.00     99.16
           !
   0.2000  !*****                                                                         1    119     0.84    100.00
           !
           ----+----+----+----+----+----+----+----+----+----+----+----+----+----+----+
               1    2    3    4    5    6    7    8    9   10   11   12   13   14   15

                                    FREQUENCY
```

1/ (PEM-FSM) / FSM

attainment of an accuracy level within ±10 percent of nominal. Additionally, since relatively extensive ruggedness testing was performed on the method during its development phase and since that testing revealed no significant interference under normally encountered sampling conditions, a measure of accuracy may be inferred from the analyses of control and blank samples. After allowing time for conditioning of new sampling bags, the ability of the method to correctly analyze standard atmospheres varied from ±0.3 ppm at 3.6 ppm to ±1.0 at 40 ppm. The method analyzed zero-level samples to within ±0.1 ppm. During the conditioning of the bags, the variation in the analysis of standards was somewhat greater.

6.4 Results of Statistical Analysis

Using the computer data files described in Section 5.4, a detailed analysis of the data was undertaken. Results of this analysis are presented here. The population of inference - adult non-smokers in the D.C. area - is estimated to include about 1.22 million individuals. Unless specifically noted otherwise, all results shown in this section apply to this population or to some specified subgroup of this population. The results also apply only to the winter of 1982-83, as this was the period of data collection.

Subgroups of the population deemed to be of particular relevance that are used in the analyses of subsections 6.4.1, 6.4.2, and 6.4.3 were described in Section 5.4. These relate to three potential sources of carbon monoxide exposure - occupational exposure, exposure through travel/commuting, and exposure through gas cooking. Some of the results in this section are also shown by type of day -- days of high potential CO exposure versus other days; and weekdays versus weekend days (actually, Friday evening through Sunday evening).

Subsections 6.4.1 and 6.4.2 present the results of statistical analyses of the BAF file. Subsection 6.4.1 provides results from analyses of the exposure levels from PEMs as indicated by hourly CO concentrations, by mean and maximum hourly CO concentrations, and by maximum 8-hour concentrations. Subsection 6.4.2 presents the results of the analysis of breath CO levels. Subsection 6.4.3 provides the analytical results relating to individuals' activities and environments and their associated CO exposures. Finally, subsection 6.4.4 investigates the measurement variability of hourly CO exposures through analyses of the duplicate-sample CO data.

Except for the duplicate sample analyses, all of the estimates are representative of the population (or subpopulations) of adult non-smokers in the Washington area, since weighted analyses were performed. Standard errors of estimates were produced by using SESUDAAN, a SAS (Statistical Analysis System) procedure developed by RTI for analysis of data from complex sample surveys (see Shah, [1981]).

It should be recognized that time periods over which data were available for different sample individuals are different in two respects:

(1) Different days are involved, since only a single sampling "day" was utilized for each person. (From a purely statistical standpoint, a much longer sampling period , e.g., several weeks, would have been used if data throughout such an extended period could have been anticipated, and if a much larger number of PEMs had been available for the study).

(2) Some variations in the starting times and lengths of sampling periods occur, due partly to variations in the times at which interviewer/respondent contacts could be made, and due partly to monitor malfunctions.

A principal impact of the first point is that estimates for subsets of days are unreliable unless a large number of days are involved. Hence, the results shown in this section apply to an "average" winter "day" in 1982-83 (or to an "average day" within some specified subset of days involving a large number of samples -- e.g., weekdays or weekend days). No attempt was made to adjust for the unequal sampling weights and sample sizes occurring for different types of days (e.g., in order to achieve equal representation of the days of the week or the relative representation of the number of days within months -- see Table 5.4.3). This approach was taken not only because of the types of estimated parameters deemed to be of most importance, but also because of the problems that would be encountered in making such adjustments, given point (2) above. That is, with only 18 to 26 hours of monitoring/activity information available for individuals, over varying sampling periods, it was not really feasible to construct such day-specific variables. The activity "sleep", for instance, overlaps types of days for most individuals.

The net result of the above problems/decisions is that analytical results labeled and described in terms of a specific subset of days (e.g., "weekend days") are actually estimated from the data of individuals who were _sampled_ on specific days. For example, "estimates for weekend days" is more precisely stated as "estimates for persons whose monitoring periods began on Friday or Saturday evenings, assuming that a census of the inference population had been conducted in the same manner as actually employed (on a sample basis) in this study". True coverage of _both_ the person _and_ time dimensions of the inference population was not practical because of the small number of available monitors per day; the reliability of the monitors; and the degree of nonresponse experienced due to individuals' unavilability for, or unwillingness to participate in, the various phases of the study. Because of the emphasis of the study -- namely, information on personal activities, environments, and associated CO exposure levels -- the person dimension was given priority over the time dimension in the study design and during the development of nonresponse adjustment strategies.

With regard to point (2) above -- that durations and starting times of individuals' sampling periods vary -- several potential impacts should be noted. First, in conjunction with the time-inference issues and concomitant nonresponse adjustment decisions described in the previous paragraph, it is clear that certain biases in the estimates may be present relative to the time dimension. (Potential biases in the person dimension can also occur whenever nonresponse is present. This was addressed in Sections 5.1 and 6.1). For example, in estimating a diurnal pattern for "weekend days", the timing of the sampling intervals (see Table 5.4.1) suggests that Friday hours will be somewhat overrepresented relative to Sunday hours for some hours of the day (and vice-versa for certain other hours of the day).

Secondly, it is apparent that similar types of biases may occur with regard to estimates of time durations and of CO exposures of particular activities and environments. In terms of the available data, for instance, certain activities may have been curtailed when an interviewer arrived at the respondent's home to either start or conclude the data collection. Hence, estimates of time durations of activities frequently occurring at times near the termination (or initiation) of the sampling period (usually early evening) may be underestimated. To the extent that the study induced respondents to be at home at the prescribed starting or ending time of the sampling period, such estimates may also suffer from so-called Hawthorne effects.

The above-described limitations (related to the time dimension of the inferences) need to be considered carefully when interpreting the results presented later in this section. However, as previously indicated, the emphasis of the study relates to the person dimension, so that they should not be considered as severe limitations on the study nor as severe reservations concerning the basic inferences and conclusions of the study. It should be emphasized, for instance, that many of the potential biases described above are indirectly reflected (e.g., in standard error estimates) as a part of the person dimension, in that the sampling error includes day-to-day variation as well as person-to-person variation.

6.4.1 Analysis of Hourly CO Exposure Data

Diurnal Patterns. Table 6.4.1 shows the mean diurnal patterns of CO exposures estimated for the Washington area population of inference. These (weighted) estimates, and their approximate standard errors, are given for all days, for weekdays and weekend days, and for days of low and high CO levels (as indicated by fixed site monitors).

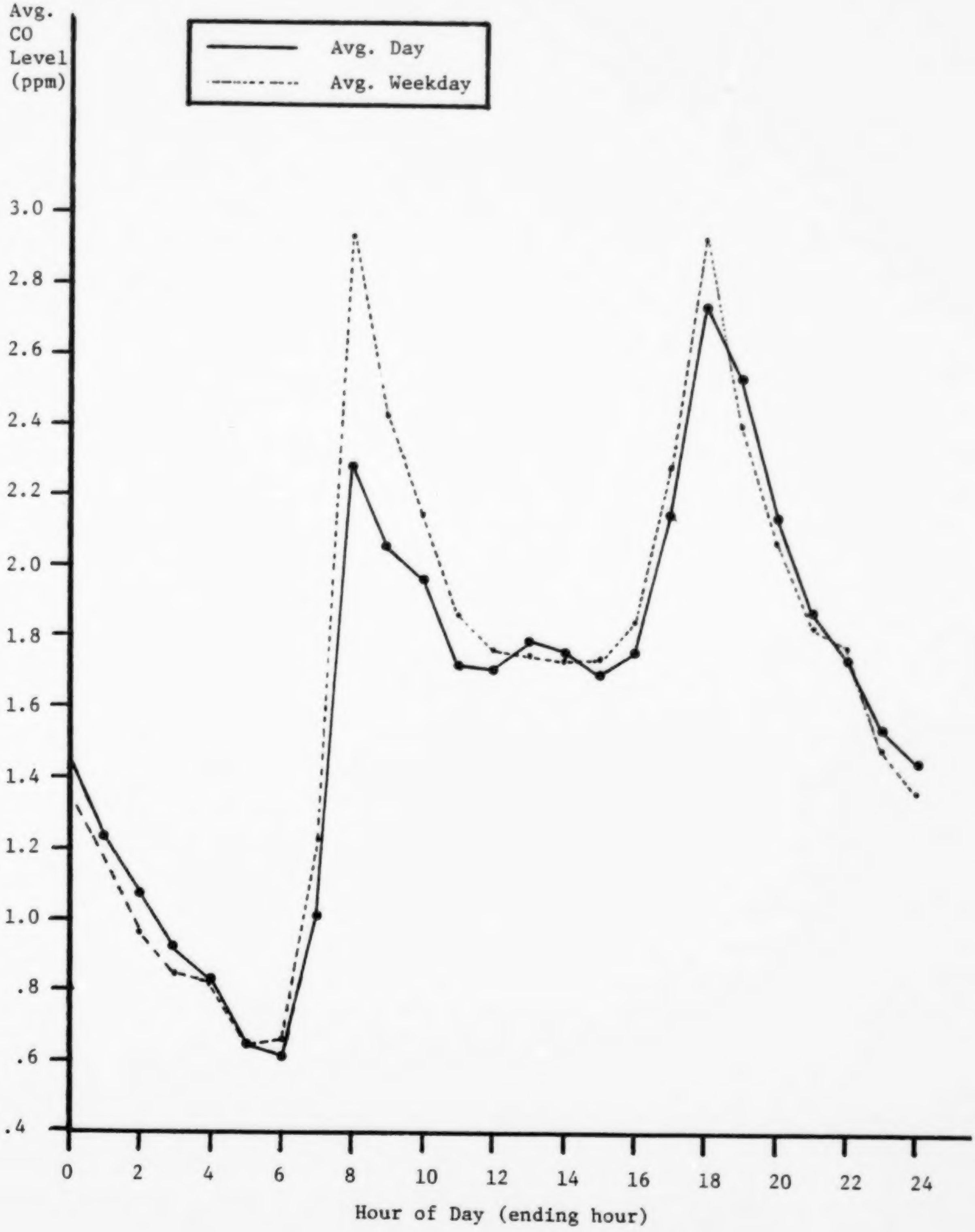
The pattern for weekdays (and, hence, for all days) exhibits the well-known effect of commuting traffic, with dramatic increases in CO levels between 7-9 a.m. and 4-7 p.m. The lowest levels occur between 4-6 a.m. For weekend days, the increase in CO level during the morning is much less pronounced than that for weekdays. The p.m. peak is of about the same magnitude, however. The late night and early morning hours also appear to have higher CO levels on weekend days, although this difference cannot be declared as statistically significant. Figure 6.4.1 shows the estimated mean diurnal exposure patterns for weekdays and for all days.

Table 6.4.1 Estimates of Mean Population CO Exposure Levels (ppm) -- Diurnal Patterns by Time of Week and Type of Day

Hour of Day (EST)	All Days		Weekdays		Weekend Days		Low CO Days		High CO Days 1/	
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
00 - 01	1.23	.14	1.15	.07	1.42	.41	1.11	.17	1.62	.15
01 - 02	1.07	.15	0.96	.07	1.32	.42	0.97	.18	1.39	.15
02 - 03	0.91	.13	0.85	.06	1.06	.37	0.84	.15	1.16	.14
03 - 04	0.82	.16	0.81	.11	0.87	.30	0.78	.19	0.98	.13
04 - 05	0.65	.07	0.64	.05	0.67	.20	0.60	.08	0.81	.11
05 - 06	0.62	.05	0.66	.07	0.53	.10	0.54	.04	0.89	.14
06 - 07	1.01	.27	1.22	.37	0.51	.08	0.97	.35	1.13	.15
07 - 08	2.28	.74	2.93	1.07	0.76	.19	2.28	1.04	2.27	.32
08 - 09	2.06	.11	2.42	.17	1.21	.21	1.84	.12	2.79	.28
09 - 10	1.97	.19	2.15	.15	1.55	.36	1.78	.22	2.61	.24
10 - 11	1.72	.06	1.87	.08	1.39	.12	1.66	.06	1.95	.13
11 - 12	1.71	.13	1.77	.14	1.57	.18	1.66	.17	1.88	.15
12 - 13	1.79	.18	1.76	.10	1.86	.43	1.74	.24	1.94	.17
13 - 14	1.77	.09	1.75	.10	1.80	.16	1.84	.12	1.53	.15
14 - 15	1.70	.08	1.74	.09	1.60	.14	1.70	.14	1.71	.21
15 - 16	1.77	.13	1.84	.11	1.59	.26	1.74	.22	1.87	.26
16 - 17	2.15	.09	2.28	.17	1.84	.18	2.07	.08	2.39	.26
17 - 18	2.73	.15	2.93	.17	2.22	.25	2.68	.15	2.89	.27
18 - 19	2.53	.27	2.40	.17	2.84	.63	2.64	.32	2.14	.22
19 - 20	2.14	.19	2.08	.15	2.27	.63	2.20	.20	1.95	.21
20 - 21	1.88	.21	1.84	.27	2.00	.53	1.85	.29	1.97	.18
21 - 22	1.74	.19	1.78	.15	1.62	.38	1.63	.25	2.12	.14
22 - 23	1.54	.16	1.49	.10	1.67	.49	1.41	.19	2.00	.16
23 - 24	1.44	.17	1.36	.08	1.62	.50	1.32	.21	1.85	.16

1/ High CO days were arbritarily defined for this report as days when any of the fixed site monitors in the Washington, D.C. area (see Table 6.3.3) had at least one hour greater than 10 ppm.

Figure 6.4.1 Average CO Exposure Levels, By Hour of Day



The days designated as high CO days generally exhibited higher PEM exposures, as 20 of the 24 hourly values were higher. The difference between the hourly exposures on high and low CO days was greatest between 8 and 10 a.m. and between 9 p.m. and 1 a.m.

Maximum Hourly Concentrations. The maximum of the hourly CO concentrations for each individual (over 18 to 26 hourly values) was determined for the 712 respondents. The analysis of this variable is shown in Table 6.4.2. For each of several subgroups, this table shows the sample size, the estimated number of individuals in the population subgroup, the estimated percentage of the total population represented by the subgroup, the average maximum hourly CO concentration estimated for the subgroup, and the approximate standard error of this estimated mean. The table also characterizes the population distribution of the maximum hourly CO values by providing estimates of the percentage of the population (subgroup) having maximum hourly CO values that exceed certain specified levels (1 ppm, 2 ppm, 4 ppm, 9 ppm, 25 ppm, and 35 ppm).

For the overall population, the mean of the maximum hourly values was estimated to be 6.74 ppm (during the winter 1982-83 data collection period). As indicated in Table 6.4.2, this mean level varied by type of day, with higher maximum hourly CO values, on average, occurring on weekdays (7.35 ppm). The mean level also varied, in accordance with *a priori* expectations, depending on individuals' occupational and traveling characteristics. Persons working outside the home, especially those in occupations with potentially high exposures, exhibited higher maximum hourly CO concentrations, on average, than those persons not working outside the home. In fact, in the high-exposure occupational category (an estimated 4.63% of the overall population), about 24% exhibited a level above the one hour standard for carbon monoxide (35 ppm), and over half of this subgroup was estimated to have hourly CO exposures over 9 ppm. Figure 6.4.2 illustrates the differences in maximum hourly CO levels for the 3 occupational groups examined and Figure 6.4.3 illustrates the differences for weekdays and weekend days. As shown in Figure 6.4.4, commuters, especially those with longer traveling times, also showed higher CO exposures (based on their one-

Table 6.4.2 Summary of Maximum Hourly CO Concentration Data

Population Subgroup	# in Samp.	Est. # in Exposed Popu.	Est. % of Total Popu.	Est. Avg. CO Conc. (ppm)	Approx. SE of Av. CO Conc. (ppm)	Estimated Percent of Exposed Population With CO Concentration > X PPM X=1	X=2	X=4	X=9	X=25	X=35
All Persons All Days	712	1215539	100.00	6.74	0.46	92.97	82.93	61.76	18.23	1.88	1.28
All Persons Low CO Days ** 2/	491	1215539	100.00	6.71	0.60	92.47	81.33	58.66	17.42	2.13	1.46
All Persons High CO Days **	221	1215539	100.00	6.82	0.25	94.66	88.31	72.73	20.97	1.03	0.65
Persons Not Working Outside Home	181	362366	29.81	5.22	0.36	89.24	76.48	64.06	8.65	0.35	0.35
Persons W/Low Occupational Exposure	503	796704	65.54	6.34	0.31	94.17	84.69	58.30	19.86	0.72	0.10
Persons W/High Occupational Exposure 1/	27	56244	4.63	22.11	5.64	100.00	99.47	95.86	57.03	28.11	23.95
All Persons Weekdays **	551	1215539	100.00	7.35	0.71	93.72	84.88	62.31	21.97	2.37	1.82
All Persons Weekend Days **	161	1215539	100.00	5.30	0.37	91.23	78.35	60.49	9.49	0.71	0.00
Non-Commuters (<3 Times Per Week)	105	167155	13.75	4.94	0.33	88.90	73.58	53.17	12.12	0.00	0.00
Commuters (All Travel 0-5 hrs/wk)	180	299240	24.62	5.04	0.27	95.20	80.80	54.69	7.63	0.39	0.00
Commuters (All Travel 6-10 hrs/wk)	233	415748	34.20	6.70	0.27	91.26	84.06	66.58	19.25	1.91	1.31
Commuters (All Travel 11-15 hrs/wk)	104	156340	12.86	7.08	1.51	94.27	86.57	65.17	24.84	0.68	0.00
Commuters (All Travel 16+ hrs/wk)	73	151821	12.49	12.01	3.47	95.25	89.11	69.44	36.72	8.33	6.64
Unknown Commuting Status	17	25236	2.08	5.56	0.98	100.00	91.65	55.80	15.73	0.00	0.00
Gas Stove at Residence -- Vented	187	370703	30.50	6.40	0.85	94.52	91.41	64.73	13.61	0.75	0.50
Gas Stove at Residence -- Not Vented	176	300726	24.74	7.05	0.73	98.23	90.26	66.33	21.58	2.06	0.25
No Gas Stove at Residence	325	504262	41.48	6.82	0.76	88.55	71.81	56.00	20.27	2.49	2.31
Presence of Gas Stove Unknown	24	39847	3.28	6.47	1.19	94.86	89.34	72.63	10.27	3.18	3.18

** Population counts have been adjusted to conform to those for the overall population.

1/ See Appendix K for definitions of high occupational exposure.

2/ High CO days were arbitrarily defined for this report as days when any of the fixed site monitors in the Washington, D.C. area (see Table 6.3.3) had at least one hour greater than 10 ppm.

FIGURE 6.4.2 MAXIMUM HOURLY CO CONCENTRATIONS BY OCCUPATIONAL EXPOSURE, WASHINGTON, D.C.

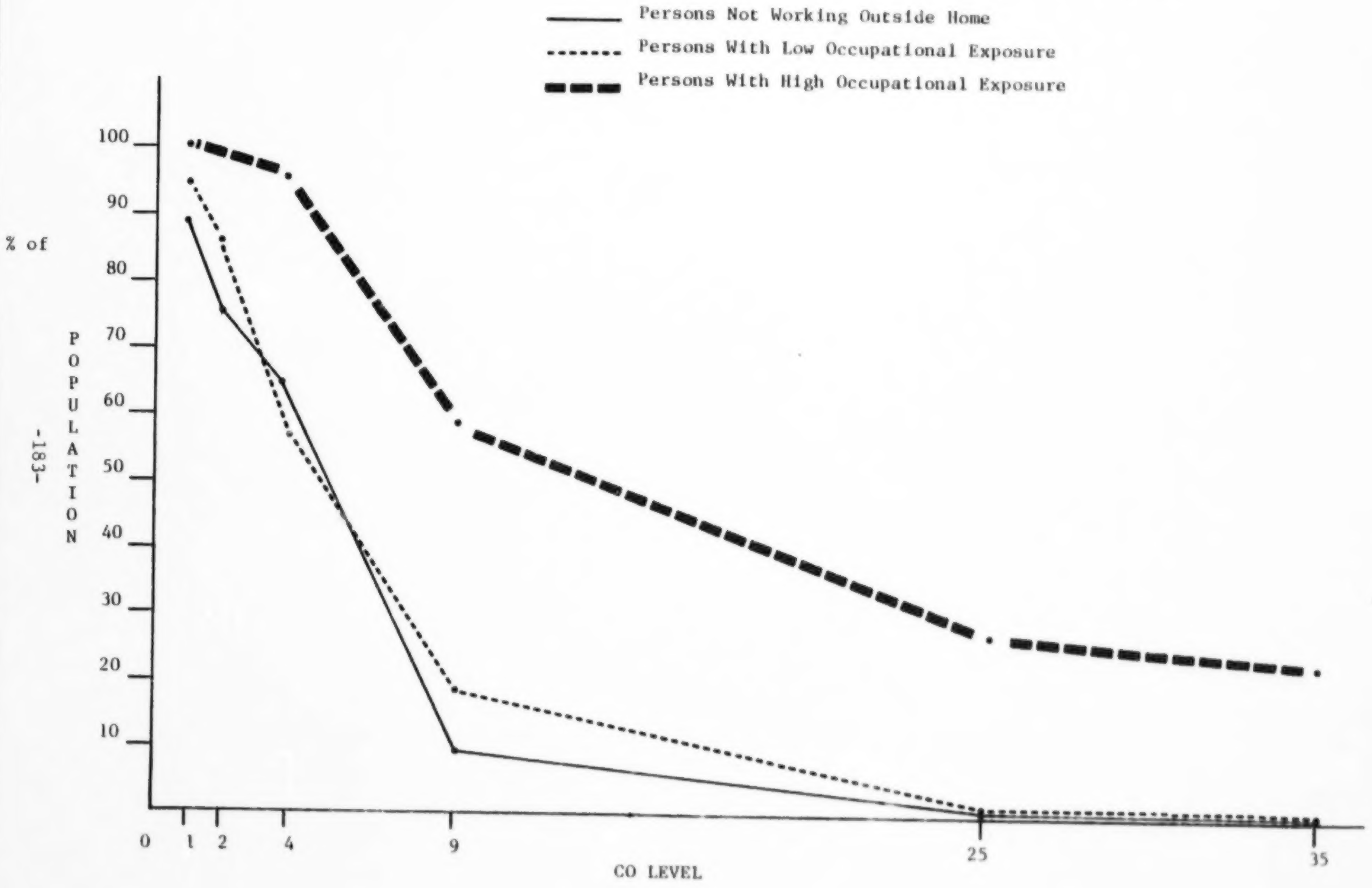


FIGURE 6.4.3 MAXIMUM HOURLY CO CONCENTRATIONS FOR WEEKDAYS AND WEEKEND DAYS, WASHINGTON, D.C.

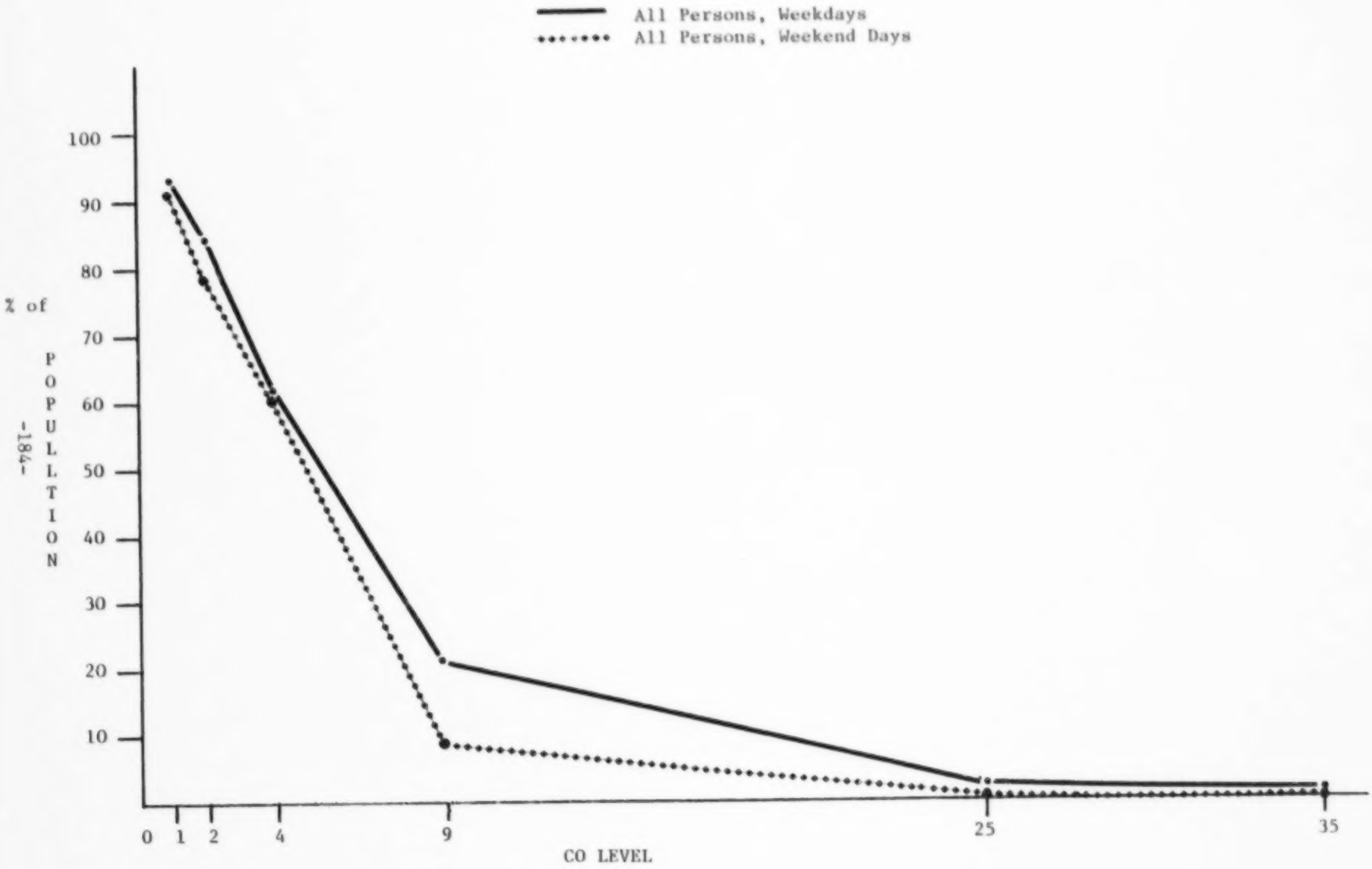
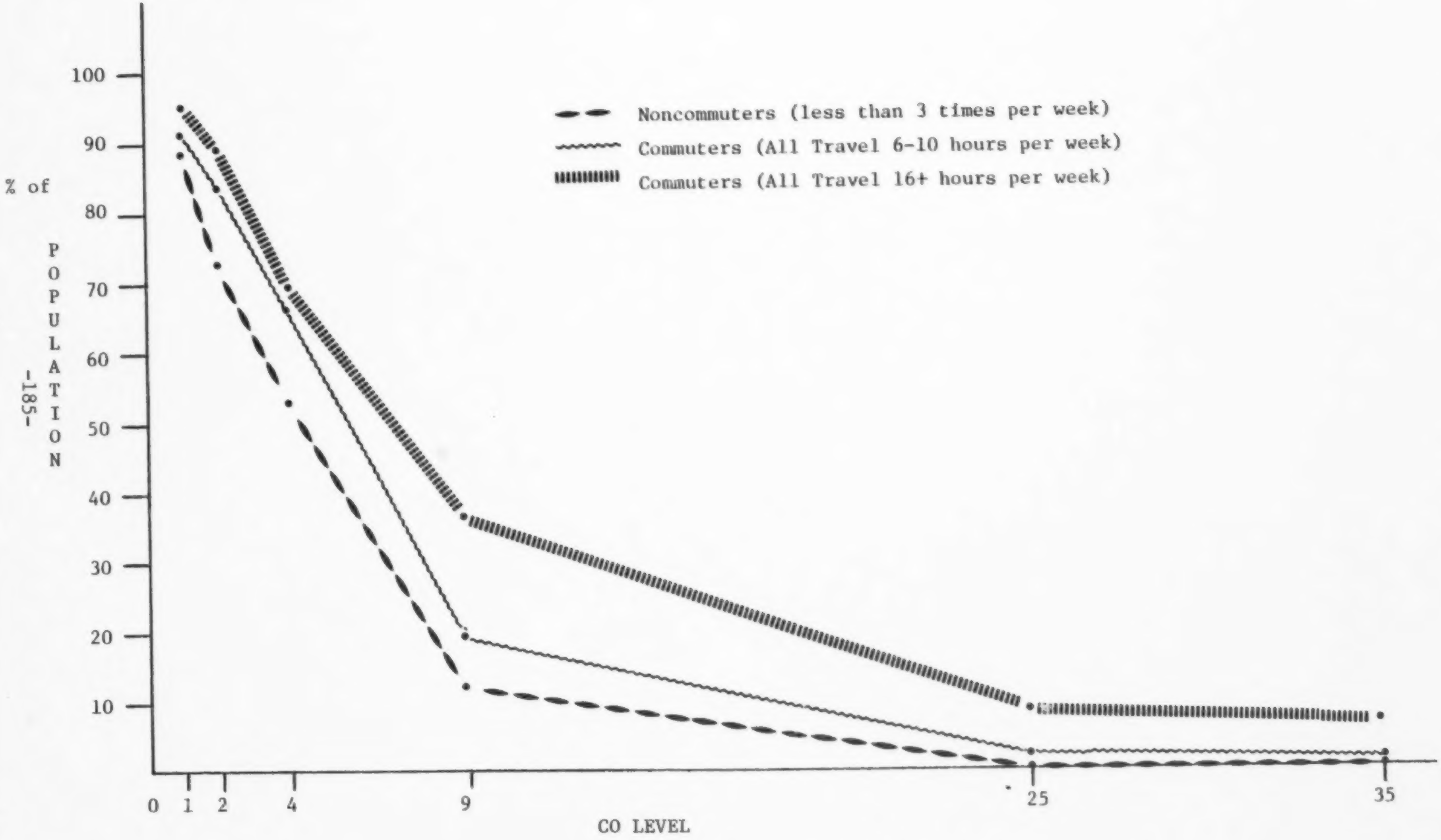


FIGURE 6.4.4 MAXIMUM HOURLY CO CONCENTRATIONS FOR SELECTED COMMUTING STATUSES, WASHINGTON, D.C.



hour maximum values) than non-commuters. Those commuters indicating total travel of more than 15 hours per week, for instance, had a mean estimated maximum hourly concentration of 12.01 ppm, as compared to 4.94 ppm for non-commuters. Persons having unvented gas stoves also showed slightly higher means than those persons not having gas stoves (an average maximum hourly concentration of 7.05 ppm versus 6.82 ppm).

Maximum 8-Hour Concentrations. Table 6.4.3 shows the results of the analysis of this exposure measure. For the overall population, the estimated mean 8-hour CO concentration was 2.79 ppm; it was estimated that about 4% of the overall population had levels exceeding 9 ppm, the 8-hour standard. These were primarily persons in high-exposure occupations and/or persons with extensive amounts of motor vehicle travel. The maximum 8-hour mean for the group with high occupational exposures was 7.51 ppm; for commuters with 16 or more hours of total travel per week, the mean was estimated to be 3.80 ppm. Persons with gas stoves in their homes also appeared to have higher 8-hour levels, on average, than persons without such stoves. In general, the only subgroup with a relatively large percentage over the 8-hour standard was the high occupational exposure group (28.1% over 9 ppm). Figures 6.4.5, 6.4.6, and 6.4.7 present the percent of the populations with maximum 8-hour CO levels greater than specified levels for various groups.

Tests Between Exposure Groups. Approximate pairwise tests of significance were conducted to determine if the various population subgroups were different in regard to their average maximum hourly and average maximum 8-hour CO exposures. The results, shown below, indicate no significant differences between low and high CO days or between the various categories of stove type. The non-significance between high and low CO days, as arbitrarily defined in this report (see Table 6.4.2), is not surprising considering that the winter of 1982-83 in Washington, D.C. was very warm and had only six days where any of the fixed stations had a maximum 8-hour average greater than the 9 ppm CO standard. Significant results are indicated for several other groups: persons not working outside the home versus those that do; persons with low occupational exposure versus those with high occupational exposure; commuters versus non-commuters; and commuters with less than 6 hours of total

Table 6.4.3 Summary of Maximum 8-Hour CO Concentration Data

Population Subgroup	# in Samp.	Est. # in Exposed Popu.	Est. % of Total Popu.	Est. Avg. CO Conc. (ppm)	Approx. SE of Av. CO Conc. (ppm)	Estimated Percent of Exposed Population With CO Concentration > X PPM					
						X=1	X=2	X=4	X=9	X=15	X=25
All Persons All Days	712	1215539	100.00	2.79	0.08	78.62	56.46	15.82	3.90	0.44	0.20
All Persons Low CO Days **	491	1215539	100.00	2.72	0.11	76.34	53.40	13.91	4.10	0.45	0.15
All Persons High CO Days **	221	1215539	100.00	3.03	0.15	86.32	66.80	22.28	3.23	0.38	0.38
Persons Not Working Outside Home	181	362366	29.81	2.35	0.18	74.55	56.19	8.55	1.01	0.00	0.00
Persons W/Low Occupational Exposure	503	796704	65.54	2.66	0.15	78.99	53.72	15.74	3.51	0.34	0.18
Persons W/High Occupational Exposure 1/	27	56244	4.63	7.51	0.68	99.47	97.33	64.01	28.11	4.70	1.88
All Persons Weekdays **	551	1215539	100.00	2.94	0.14	81.30	56.95	18.61	4.46	0.62	0.29
All Persons Weekend Days **	161	1215539	100.00	2.43	0.44	72.36	55.33	9.32	2.59	0.00	0.00
Non-Commuters (<3 Times Per Week)	105	167155	13.75	2.30	0.17	70.59	51.38	12.50	0.66	0.00	0.00
Commuters (All Travel 0-5 hrs/wk)	180	299240	24.62	2.35	0.18	75.89	52.52	7.52	1.29	0.00	0.00
Commuters (All Travel 6-10 hrs/wk)	233	415748	34.20	2.79	0.17	76.23	57.76	17.30	4.64	1.11	0.60
Commuters (All Travel 11-15 hrs/wk)	104	156340	12.86	3.22	0.82	82.38	53.86	23.52	6.76	0.45	0.00
Commuters (All Travel 16+ hrs/wk)	73	151821	12.49	3.80	0.85	93.35	65.41	24.75	8.33	0.00	0.00
Unknown Commuting Status	17	25236	2.08	2.55	0.25	91.65	77.78	10.61	0.00	0.00	0.00
Gas Stove at Residence -- Vented	187	370703	30.50	2.99	0.20	88.10	67.79	15.60	1.95	0.50	0.50
Gas Stove at Residence -- Not Vented	176	300726	24.74	3.03	0.27	90.78	65.48	19.52	3.59	0.39	0.21
No Gas Stove at Residence	325	504262	41.48	2.55	0.12	64.23	43.93	14.48	5.58	0.45	0.00
Presence of Gas Stove Unknown	24	39847	3.28	2.11	0.53	80.78	41.66	7.03	3.18	0.00	0.00

** Population counts have been adjusted to conform to those for the overall population.

1/ See Appendix K for definitions of high occupational exposure.

FIGURE 6.4.5   MAXIMUM 8 HOUR CO CONCENTRATIONS BY OCCUPATIONAL EXPOSURE, WASHINGTON, D.C.

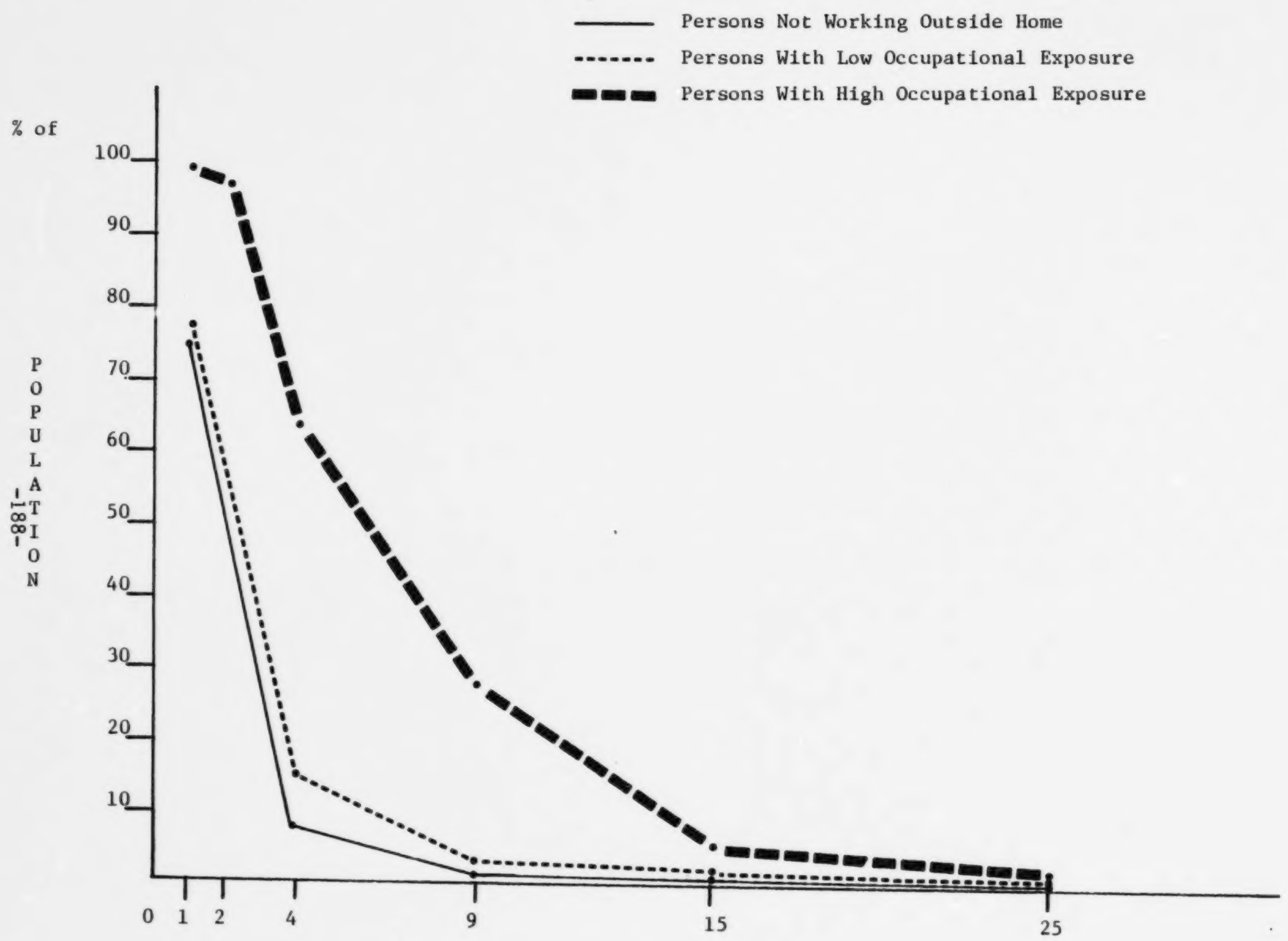


FIGURE 6.4.6 MAXIMUM 8-HOUR CO CONCENTRATIONS FOR WEEKDAYS AND WEEKEND DAYS, WASHINGTON, D.C.

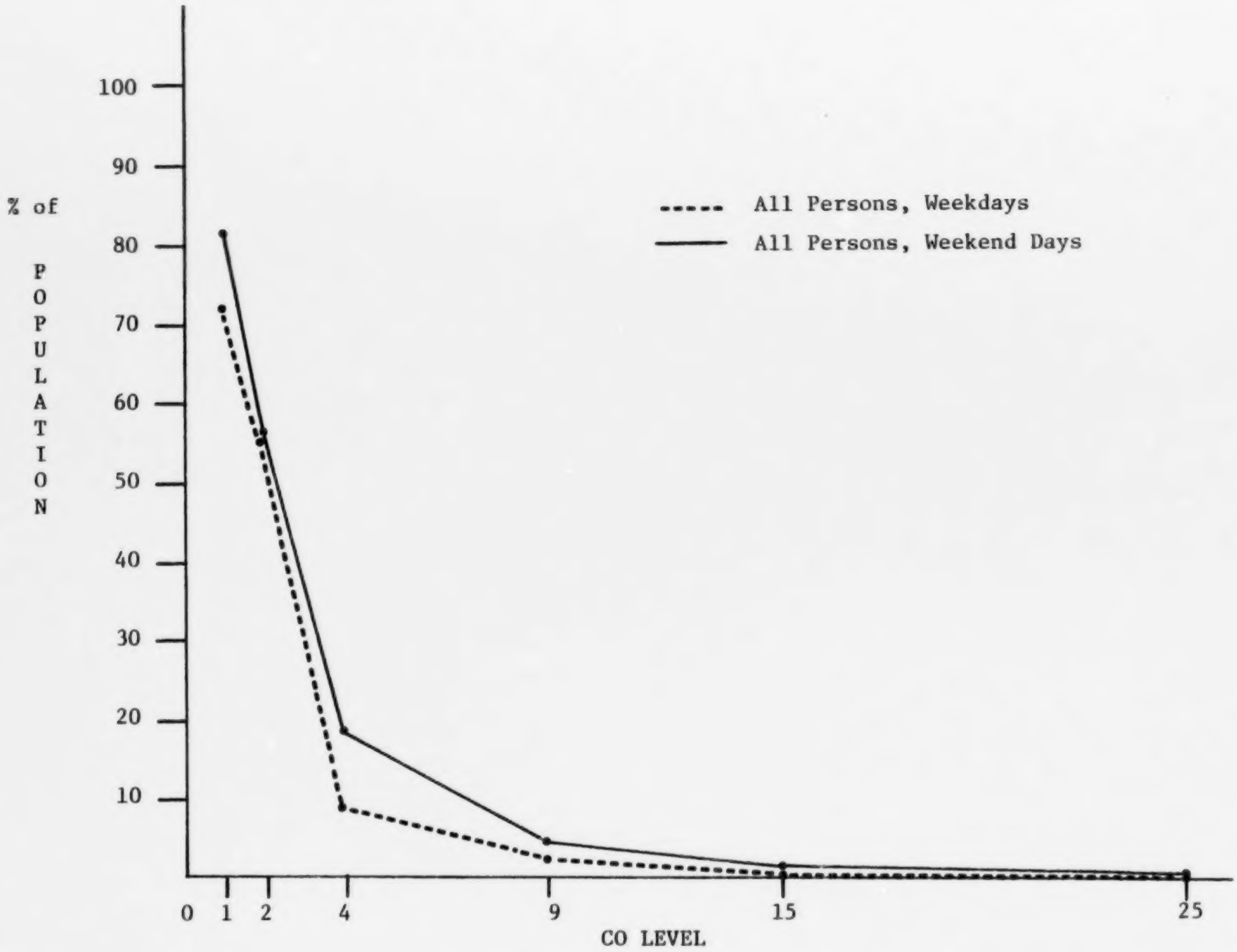
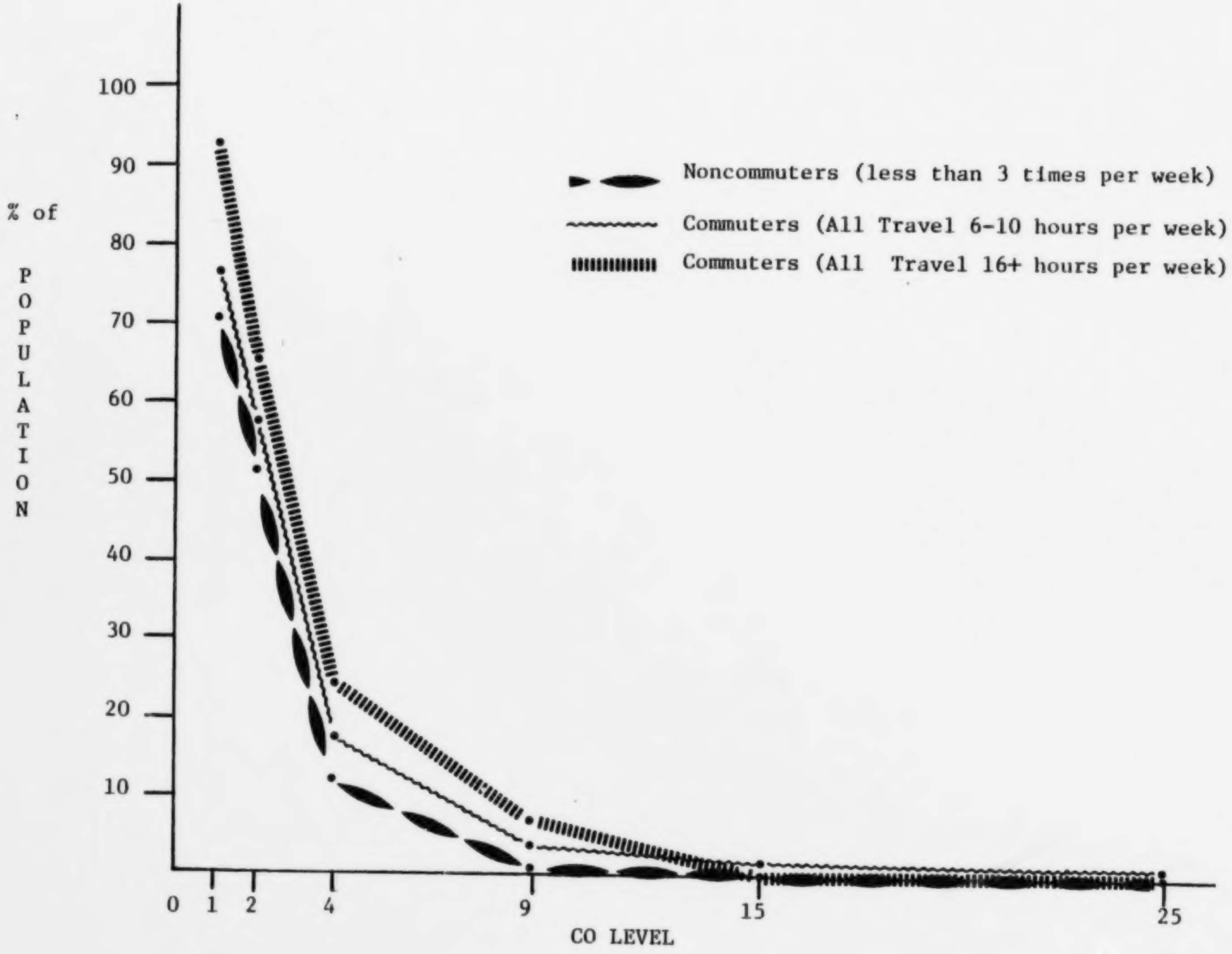


FIGURE 6.4.7 MAXIMUM 8-HOUR CO CONCENTRATIONS FOR SELECTED COMMUTING STATUSES, WASHINGTON, D.C.



travel per week versus commuters with 6 or more hours per week. Weekdays versus weekend days are significantly different only for the one hour maximum. The tests are only approximate; the asterisks indicate statistical significance at the 5% level and no asterisk indicates the test was not significant at the .05 level.

Population Subgroup	Average of Maximum 1-Hour CO Conc (ppm)	Average of Maximum 8-Hour CO Conc (ppm)
Low CO days	6.71	2.72
High CO days	6.82	3.03
Weekdays	7.35*	2.94
Weekend days	5.30	2.43
Gas stove at residence-vented	6.40	2.99
Gas stove at residence-unvented	7.05	3.03
Gas stove at residence-unvented	7.05	3.03
No gas stove at residence	6.82	2.55
Persons not working outside home	5.22	2.35
Persons working outside home	7.38*	2.98*
Persons with low occupational exposure	6.34	2.66
Persons with high occupational exposure	22.11*	7.51*
Non-commuters (less than 3 times/week)	4.94	2.30
Commuters	7.06*	2.88*
Commuters--all travel = 0 - 5 hrs/wk	5.04	2.35
Commuters--all travel = 6+ hrs/wk	7.90*	3.09*

Mean Hourly Concentrations. Table 6.4.4 presents the results for the mean hourly concentrations (over all available hours) in the same format as for the previous two variables. The overall average was 1.61 ppm. The patterns exhibited for the various subgroups are similar to those evidenced for the maximum one-hour and maximum eight-hour variables. Again, the high-exposure occupation subgroup stood out as the group with highest overall levels.

Table 6.4.4 Summary of Mean Hourly CO Concentration Data

Population Subgroup	# in Samp.	Est. # in Exposed Popu.	Est. % of Total Popu.	Est. Avg. CO Conc. (ppm)	Approx. SE of Av. CO Conc. (ppm)	Estimated Percent of Exposed Population With CO Concentration > X PPM				
						X=1	X=2	X=4	X=9	X=15
All Persons All Days	712	1215539	100.00	1.61	0.07	60.30	27.20	5.88	0.35	0.06
All Persons Low CO Days **	491	1215539	100.00	1.55	0.09	58.02	24.65	6.17	0.34	0.08
All Persons High CO Days **	221	1215539	100.00	1.83	0.10	67.97	35.78	4.90	0.38	0.00
Persons Not Working Outside Home	181	362366	29.81	1.47	0.18	58.61	32.22	1.35	0.00	0.00
Persons W/Low Occupational Exposure	503	796704	65.54	1.53	0.08	58.43	21.21	5.94	0.40	0.10
Persons W/High Occupational Exposure 1/	27	56244	4.63	3.61	0.30	97.38	79.75	34.19	1.88	0.00
All Persons Weekdays **	551	1215539	100.00	1.68	0.07	62.17	26.48	7.28	0.49	0.09
All Persons Weekend Days **	161	1215539	100.00	1.46	0.28	55.91	28.88	2.59	0.00	0.00
Non-Commuters (<3 Times Per Week)	105	167155	13.75	1.33	0.11	48.87	23.35	1.22	0.00	0.00
Commuters (All Travel 0-5 hrs/wk)	180	299240	24.62	1.49	0.17	56.19	31.79	1.86	0.00	0.00
Commuters (All Travel 6-10 hrs/wk)	233	415748	34.20	1.59	0.09	58.86	23.14	5.32	0.84	0.19
Commuters (All Travel 11-15 hrs/wk)	104	156340	12.86	1.82	0.40	59.27	28.88	14.97	0.45	0.00
Commuters (All Travel 16+ hrs/wk)	73	151821	12.49	2.01	0.36	83.77	31.14	12.06	0.00	0.00
Unknown Commuting Status	17	25236	2.08	1.54	0.15	73.55	30.99	0.00	0.00	0.00
Gas Stove at Residence -- Vented	187	370703	30.50	1.89	0.09	72.86	40.43	4.23	0.50	0.21
Gas Stove at Residence -- Not Vented	176	300726	24.74	1.78	0.18	72.97	27.26	7.12	0.55	0.00
No Gas Stove at Residence	325	504262	41.48	1.34	0.09	45.18	18.50	6.48	0.14	0.00
Presence of Gas Stove Unknown	24	39847	3.28	1.20	0.25	38.98	13.74	4.20	0.00	0.00

** Population counts have been adjusted to conform to those for the overall population.

1/ See Appendix K for definitions of high occupational exposure.

6.4.2 Analysis of CO Breath Measurements

Breath samples taken at the end of each individuals' monitoring period (late afternoon or early evening) were analyzed to determine CO concentrations. These measurements were available for 659 sample members. The results of the analysis of these data are shown in Table 6.4.5. The overall mean CO concentration for the population was estimated to be 5.12 ppm (with a standard error of .07 ppm). Among the subgroup categories shown in the table, little variation in this mean level is evidenced. About 95% of the overall population exhibited breath CO levels in the range from 1 to 10 ppm. The lack of extreme variation is perhaps due to the fact that (almost) all of the breath measurements were made in the same type of environment (i.e., in the respondents' homes rather than while commuting or on-the-job). Higher mean levels were, nevertheless, observed for persons with high exposure occupations and with large amounts of travel.

6.4.3 Analysis of Activities and Associated CO Exposures

As indicated in Section 5.4.2.2, analysis of the Activity Analysis File (AAF) data required additional processing prior to analysis. Based upon frequency counts of the various activity and location codes (see Exhibit 5.4.2), a set of five major and sixteen minor environments were developed. These were the following:

Table 6.4.5 Summary of Breath CO Concentration Data

Population Subgroup	No. in Sample	Est. Avg. CO Conc. (ppm)	Appx. S.E. of Avg. CO Conc. (ppm)	Est. % of Exposed Population With CO Concentration > X PPM				
				X=2	X=5	X=10	X=15	X=20
All Persons - All Days	659	5.12	0.07	96.81	33.25	5.14	2.07	0.66
All Persons - Low CO Days	457	5.18	0.09	96.39	31.92	5.64	2.32	0.86
All Persons - High CO Days	202	4.93	0.26	98.20	37.59	3.53	1.26	0.00
Persons Not Working Outside Home	172	4.79	0.22	96.31	28.16	4.25	4.12	1.00
Persons w/Low Occup. Exposure	462	5.20	0.13	97.05	34.91	4.94	1.18	0.56
Persons w/High Occup. Exposure	24	6.11	0.88	96.39	41.08	14.56	2.66	0.00
All Persons - Weekdays	506	5.03	0.12	97.68	33.39	3.09	1.51	0.78
All Persons - Weekend Days	153	5.36	0.21	94.61	32.88	10.39	3.51	0.37
Non-Commuters (<3 times per wk)	98	5.43	0.67	98.07	34.86	8.31	8.07	1.90
Commuters-All Travel=0-5 hrs/wk	171	4.81	0.21	95.82	28.36	1.67	0.81	0.43
Commuters-All Travel=6-10 hrs/wk	216	4.90	0.30	95.82	32.39	3.35	1.12	0.82
Commuters-All Travel=11-15 hrs/wk	98	5.38	0.46	97.34	36.51	7.68	0.00	0.00
Commuters-All Travel=16+ hrs/wk	62	6.00	0.36	100.00	43.09	11.01	2.75	0.00
Unknown Commuting Status	14	3.35	0.40	93.55	7.25	0.00	0.00	0.00
Gas Stove at Residence-Vented	173	5.44	0.53	98.60	43.10	3.29	2.14	1.25
Gas Stove at Residence-Not Vented	168	5.36	0.22	98.73	43.99	4.29	1.14	0.38
No Gas Stove at Residence	299	4.83	0.30	94.75	22.24	6.80	2.45	0.24
Presence of Gas Stove Unknown	19	4.35	0.87	93.33	5.69	5.69	4.36	4.36

Major Environments	Minor Environments
In transit	walking, jogging, bicycling
	car
	other travel
Indoors - at residence	sleeping
	cooking - gas stove
	cooking - other or unknown
	all other activities
Indoors - not at residence	office
	store
	restaurant
	parking garage
	other
Outdoors	near road, construction site or service station
	parking area
	other
Unknown	

The time spent in each of these environments was determined by adding times over the activity segments in the AAF for each sample member. Similarly, by time-weighting the activity segments, the average CO exposure level for each individual was determined for each environment.

In addition to the environments, times and CO levels by activity type were determined in a similar manner. The "sleep" activity was separated from the "suspected sleep" activity in this case, whereas for the environments shown above, these two types of segments were treated as one.

Section 6.4.3.1 below examines the activity patterns and environments in terms of time durations. The next subsection then deals with the associated CO exposure levels.

6.4.3.1 Activity and Location Patterns

Table 6.4.6 characterizes the activity patterns of the adult non-smoking population in the D.C. area for the winter of 1982-83. The table shows the estimated number of individuals who were involved in a particular activity (i.e., the number of persons exposed to CO through the given activity). Then, for this exposed population, the amount of time involved in the activity is then characterized by the mean time duration (and its standard error), and by selected percentiles

Table 6.4.6 Summary of Population Estimates Relating to the Number of Individuals Involved In, and Amount of Time Spent In, Various Types of Activities

Activity	No. in Sample	Est. No. in Exposed Population	Estimated % of Total Population	Distribution of Time Durations for Exposed Population (Hrs) Average Duration (hrs)	Std. Error	Est. Population Percentiles 10	25	50	75	90
Transit, travel	662	1,141,746	93.93	2.07	0.15	0.47	0.93	1.55	2.67	4.04
Work, business meeting	403	613,632	50.48	6.63	0.27	2.41	5.28	7.36	8.43	9.30
Cooking	337	607,486	49.98	2.14	0.08	0.45	0.87	1.43	2.66	5.08
Laundry	74	178,111	14.65	0.85	0.10	0.25	0.52	0.52	1.00	1.62
Inside House - chores	278	481,602	39.62	2.18	0.18	0.30	0.62	1.65	2.77	4.67
Outside House - chores	74	138,665	11.41	1.00	0.26	0.08	0.11	0.48	2.07	2.21
Errands, shopping, etc.	273	434,786	35.77	0.75	0.14	0.08	0.20	0.45	0.88	1.43
Personal activities	539	963,133	79.24	1.10	0.04	0.22	0.38	0.75	1.30	2.03
Leisure activities	520	886,852	72.96	3.68	0.34	0.50	1.35	3.19	4.98	7.67
Misc. - including suspected sleep	118	183,226	15.07	10.64	0.23	7.58	8.97	10.10	11.88	14.27
Sleeping	597	1,044,983	85.87	8.62	0.18	6.60	7.53	8.48	9.62	11.65
School, study	56	101,216	8.33	2.97	0.29	0.28	1.35	2.13	3.47	6.75
Eating, drinking	463	795,926	65.48	1.78	0.42	0.35	0.57	1.20	2.16	4.58
Sports and exercise	84	127,883	10.52	1.16	0.06	0.39	0.78	1.07	1.47	1.77
Church, political meeting, etc.	43	60,010	4.94	1.85	0.15	0.85	1.03	1.53	2.18	3.02
Inside House - misc.	37	567,808	46.71	2.21	0.11	0.17	0.58	1.73	3.17	4.93
In parking garage or lot	82	129,018	10.61	0.30	0.05	0.07	0.08	0.12	0.30	0.73
Outside, not otherwise specified	87	159,063	13.09	0.48	0.05	0.08	0.13	0.35	0.66	0.79
Doctor or Dentist Office	26	43,774	3.60	0.85	0.13	0.32	0.38	0.59	0.89	1.48
Unknown	496	890,524	73.26	1.30	0.12	0.05	0.10	0.38	1.97	3.90

-- namely the 10th, 25th, 50th (median), 75th, and 90th percentiles. The table indicates, for instance, that about 40% of the total population engaged in the activity "indoor chores". For these 481,602 (est.) individuals, the mean amount of time in this activity was 2.18 hours and the median time duration was 1.65 hours. The remaining 60% of the total population did not engage in this activity (i.e., had a time duration of zero hours). The table shows that the average time spent in "transit, travel" was 2.07 hours (among those persons with this activity during an 18-26 monitoring period), that "workers" averaged 6.63 hours at work, etc.

Table 6.4.7 shows, in a similar format, the time duration analysis with respect to the five major environments and the sixteen minor environments. This table indicates that the average time indoors at the residence was 17.63 hours. The mean time in a parking garage (for those so exposed) was 48 minutes; however, the median time was only 11 minutes. This indicates, as might be expected, a highly skewed distribution.

6.4.3.2 Carbon Monoxide Exposures

Table 6.4.8 shows estimates of the CO exposure levels for the various activity types. The estimates apply only to those persons actually involved in the particular activity. The table shows the mean CO exposure level and its estimated standard error, along with estimates of the proportions of the exposed population having CO exposure levels above specified levels (1, 2, 4, 9, 25, and 35 ppm). Note that 28.2% of the population exposed to CO in parking garages experienced CO levels above 9 ppm while in that environment.

Some of the key information in this table was extracted and reformatted to produce Table 6.4.9; in Table 6.4.9, the activities have been reordered in accordance with the estimated mean CC levels (from highest to lowest). Table 6.4.9 also furnishes population percentile estimates for the 10th, 25th, 50th (median), 75th, and 90th percentile points.

Two general observations concerning the results of Table 6.4.9 that deserve mentioning are:

(1) The ranking of activities, with minor exceptions, is as one would expect (e.g., in parking garage and in transit have, by far, the highest averages). There is considerable overlap in

Table 6.4.7 Summary of Population Estimates Relating to the Number of Individuals Exposed To, and Amount of Time Spent In, Various Types of Environments

				Distribution of Time Durations for Exposed Population (Hrs)						
						Est. Population Percentiles				
Type of Environment	No. in Sample	Est. No. in Exposed Population	Estimated % of Total Population	Average Duration (hrs)	Std. Error	10	25	50	75	90
In Transit	662	1,141,746	93.93	2.07	0.15	0.47	0.93	1.55	2.67	4.04
walk, jog, bicycle	226	355,550	29.25	0.82	0.11	0.08	0.25	0.53	0.98	1.76
car	592	1,029,688	84.71	1.76	0.07	0.33	0.75	1.32	2.13	3.40
other	130	214,632	17.66	1.25	0.09	0.20	0.32	0.82	1.53	2.69
Indoors - At Residence	705	1,215,539	100.00	17.63	0.31	12.38	13.92	17.47	21.51	23.30
sleep *	705	1,215,539	100.00	9.01	0.07	6.78	7.68	8.75	9.95	11.79
cook - gas stove	186	405,334	33.35	1.96	0.21	0.42	0.75	1.41	2.28	5.50
cook - other or unknown	192	279,487	22.99	1.79	0.13	0.20	0.67	1.37	2.67	3.70
other	701	1,203,513	99.01	7.63	0.20	3.32	4.60	6.99	10.26	12.99
Indoors - Not at Residence	583	924,540	76.06	5.44	0.19	0.52	1.53	6.35	8.61	9.52
office	349	534,110	43.94	5.80	0.17	0.34	2.54	7.14	8.38	9.23
store	225	372,479	30.64	1.42	0.07	0.13	0.22	0.60	1.30	4.86
restaurant	170	313,488	25.79	1.19	0.15	0.22	0.41	0.75	1.32	2.31
parking garage	59	87,187	7.17	0.81	0.29	0.07	0.10	0.18	0.45	1.11
other	257	383,216	31.53	2.49	0.16	0.13	0.47	1.42	3.53	7.33
Outdoors	243	407,695	33.54	0.96	0.09	0.08	0.13	0.35	1.17	2.82
near road, gas station, construction site	164	291,354	23.97	0.84	0.17	0.07	0.10	0.33	0.88	2.74
parking area	54	80,893	6.65	0.32	0.05	0.07	0.08	0.13	0.31	0.72
other	79	109,022	8.97	1.11	0.19	0.10	0.27	0.53	1.07	2.65
Unknown	4	11,032	0.91	0.28	0.08	----	----	----	-----	-----

* Estimates may be biased due to inclusion of other activities for some sample members.

Table 6.4.8 Summary of CO Exposure Levels, By Type of Activity

Activity	# in Samp.	Est. # in Exposed Popu.	Est. % of Total Popu.	Est. Avg. CO Conc. (ppm)	Approx. SE of Av. CO Conc. (ppm)	Avg. Time Duration (Hrs)	Estimated Percent of Exposed Population With CO Concentration > X PPM					
							X=1	X=2	X=4	X=9	X=25	X=35
Transit, Travel	662	1141746	93.93	4.51	0.17	2.07	91.09	76.44	43.79	8.76	0.31	0.25
Work, Business Meeting	403	613632	50.48	1.97	0.13	6.63	50.74	24.10	10.34	5.24	0.28	0.00
Cooking	337	607486	49.98	2.10	0.18	2.14	63.03	43.72	14.27	2.42	0.00	0.00
Laundry	74	178111	14.65	1.57	0.63	0.85	50.45	34.57	4.09	0.00	0.00	0.00
Inside House - Chores	278	481602	39.62	1.70	0.40	2.18	52.89	39.10	4.88	0.39	0.00	0.00
Outside House - Chores	74	138665	11.41	0.89	0.24	1.00	31.20	7.69	1.14	1.14	0.65	0.00
Errands, Shopping, Etc.	273	434786	35.77	2.50	0.25	0.75	69.74	47.12	18.24	2.68	0.00	0.00
Personal Activities	539	963133	79.24	1.35	0.05	1.10	42.26	25.44	5.93	1.11	0.00	0.00
Leisure Activities	520	886852	72.96	1.49	0.18	3.68	47.55	27.31	6.60	0.46	0.04	0.04
Miscellaneous - Including Suspected Sleep	118	183226	15.07	1.10	0.12	10.64	43.36	10.57	4.03	1.38	0.00	0.00
Sleeping	597	1044983	85.97	0.85	0.11	8.62	30.09	9.17	2.00	0.21	0.00	0.00
School, Study	56	101216	8.33	1.79	0.28	2.97	34.60	17.39	12.06	7.16	0.00	0.00
Eating, Drinking	463	795926	65.48	1.99	0.22	1.78	56.17	37.55	10.99	1.51	0.00	0.00
Sports and Exercise	84	127883	10.52	1.21	0.42	1.16	34.26	15.45	4.21	2.02	0.00	0.00
Church, Political Meetings, Etc.	43	60010	4.94	0.91	0.20	1.85	24.58	12.49	4.55	0.00	0.00	0.00
Inside House - Miscellaneous	337	567808	46.71	1.28	0.20	2.21	40.67	18.52	5.01	1.06	0.00	0.00
In Parking Garage or Parking Lot	82	129018	10.61	6.93	0.74	0.30	80.50	61.32	40.65	28.23	3.27	1.98
Outside, Not Otherwise Specified	87	159063	13.09	1.74	0.21	0.48	54.67	23.77	12.84	2.30	0.00	0.00
Doctor or Dentist Office	26	43774	3.60	2.07	0.65	0.85	64.44	26.70	5.51	5.51	0.00	0.00
Unknown	496	890524	73.26	1.86	0.15	1.30	51.35	30.92	9.52	3.57	0.12	0.00

Table 6.4.9 Summary of CO Exposure Levels, By Type of Activity -- Ranked According to Mean CO Level

Type of Activity	Estimated Size of of Exposed Population, as Percent of Total Population	Average Time Duration (hours)	Est. Average CO Conc. (ppm)	Estimated % of Exposed Popu. With CO Level > 4 ppm	Percentile Estimates of Exposed Population CO Levels (ppm), Selected Percentile Points				
					10	25	50	75	90
In parking garage or lot	10.61	0.30	6.93	41	0.26	1.41	3.33	11.03	21.35
Transit, travel	93.93	2.07	4.51	44	1.03	2.16	3.49	6.20	8.42
Errands, shopping	35.77	0.75	2.50	18	0.10	0.84	1.84	3.14	4.83
Cooking	49.98	2.14	2.10	14	0.05	0.44	1.54	3.17	4.39
Doctor or dentist office	3.60	0.85	2.07	6	0.05	0.50	1.29	2.03	2.64
Eating, drinking	65.48	1.78	1.99	11	0.05	0.41	1.40	3.07	4.04
Work, business meeting	50.48	6.63	1.97	10	0.05	0.40	1.05	1.93	4.10
Unknown activity	73.26	1.30	1.86	10	0.05	0.14	1.02	2.21	3.88
School or study	8.33	2.97	1.79	12	0.05	0.07	0.74	1.63	4.49
Outside-activity unspecified	13.09	0.48	1.74	13	0.05	0.09	1.05	1.79	4.42
Inside house - chores	39.62	2.18	1.70	5	0.05	0.31	1.14	2.99	3.36
Laundry	14.65	0.85	1.57	4	0.05	0.12	0.97	3.14	3.42
Leisure activities	72.96	3.68	1.49	7	0.05	0.29	0.91	2.10	3.10
Personal activities	79.24	1.10	1.35	6	0.05	0.05	0.69	2.05	3.74
Inside house-misc. activities	46.71	2.21	1.28	5	0.05	0.15	0.79	1.67	2.77
Sports, exercise	10.52	1.16	1.21	4	0.05	0.18	0.33	1.74	2.27
Miscellaneous plus suspected sleep	15.07	10.64	1.10	4	0.05	0.06	0.81	1.38	2.10
Church, political mtg., etc.	4.94	1.85	0.91	5	0.05	0.17	0.48	0.96	2.50
Outside house - chores	11.41	1.00	0.89	1	0.05	0.05	0.30	1.12	1.21
Sleeping	85.97	8.62	0.85	2	0.05	0.05	0.33	1.26	1.96

the definitions of activities, as described previously in Section 5.4. This, along with some bias probably introduced by respondents' omissions of activities from their diaries, probably accounts for the exceptions. The most notable exceptions are the higher than expected ranking for "doctor or dentist office" and the lower-than-expected ranking of "outside house - chores".

(2) The distributions of CO exposures appear to be skewed to the right for all activities; this is indicated not only by the estimated percentiles, but also by the fact that the mean levels exceed the median levels.

Tables 6.4.10 and 6.4.11 provide summaries of the analysis of the CO exposure levels by type of environment. Because the environments were derived principally from the location codes and modes of travel indicated in respondents' diaries, there is less overlap in environment definitions than in the activity definitions. Thus, the environment results are likely to be more useful. Two principal differences in definitions between the activity and environment tables should be recognized:

(1) "sleep" in the environment tables combines two activities from the activity table -- namely, "sleeping" and "miscellaneous plus suspected sleep".

(2) The activity "in parking garage or lot" refers to both indoor and outdoor situations; in the environment table, "parking garage" and "parking area" are considered separately. (As might be expected, the results indicate higher CO levels for the indoor parking.)

Tables 6.4.10 and 6.4.11 again indicate the relatively high CO levels in parking garages (mean = 10.36 ppm, median = 4.80 ppm). The "in transit" and outdoor parking environments also exhibit relatively high levels (means of 4.51 ppm and 4.67 ppm, respectively).

Statistical tests were performed for the four major environments ("unknown" is excluded) to determine if the mean exposure levels were different. The four estimated means are shown below:

Table 6.4.10 Summary of CO Exposure Levels, by Type of Environment

Activity	# in Samp.	Est. # in Exposed Popu.	Est. % of Total Popu.	Est. Avg. CO Conc. (ppm)	Approx. SE of Av. CO Conc. (ppm)	Avg. Time Duration (Hrs)	Estimated Percent of Exposed Population With CO Concentration > X PPM					
							X=1	X=2	X=4	X=9	X=25	X=35
In Transit	662	1141746	93.93	4.51	0.17	2.07	91.09	76.44	43.79	8.76	0.31	0.23
Walk, Jog, Bicycle	226	355550	29.25	2.42	0.29	0.82	71.93	46.44	19.89	1.42	0.00	0.00
Car	592	1029688	84.71	5.05	0.14	1.76	92.35	80.08	47.37	10.65	0.93	0.36
Other	130	214632	17.66	3.59	0.30	1.25	73.09	61.19	31.92	9.96	0.00	0.00
Indoors - At Residence	705	1215539	100.00	1.19	0.10	17.63	44.18	18.90	3.15	0.30	0.00	0.00
Sleep *	705	1215539	100.00	0.88	0.09	9.01	31.99	9.13	2.25	0.39	0.00	0.00
Cook - Gas Stove	186	405334	33.35	2.78	0.20	1.96	78.73	61.56	21.93	3.67	0.00	0.00
Cook - Other or Unknown	192	279487	22.99	1.40	0.19	1.79	41.57	22.24	11.64	0.70	0.00	0.00
Other	701	1203513	99.01	1.51	0.12	7.63	50.75	26.60	6.56	0.38	0.00	0.00
Indoors - Not at Residence	583	924540	76.06	2.04	0.15	5.44	53.58	29.93	10.26	4.72	0.11	0.00
Office	349	534110	43.94	1.86	0.27	5.80	55.10	28.42	8.74	4.01	0.12	0.00
Store	225	372479	30.64	2.49	0.49	1.42	66.01	47.55	16.78	3.76	0.00	0.00
Restaurant	170	313488	25.79	2.09	0.32	1.19	60.10	37.98	11.46	0.84	0.47	0.00
Parking Garage	59	87187	7.17	10.36	4.43	0.81	81.48	74.94	53.60	34.13	8.99	8.99
Other	257	383216	31.53	1.85	0.14	2.49	41.15	21.89	11.13	5.85	0.28	0.00
Outdoors	243	407695	33.54	2.62	0.28	0.96	51.46	30.27	22.05	6.79	0.60	0.25
Near Road, Gas Sta., Construction Site	164	291354	23.97	2.65	0.20	0.84	55.46	35.51	23.45	7.57	0.49	0.00
Parking Area	54	80893	6.65	4.67	0.95	0.32	65.89	38.42	24.20	11.91	1.27	1.27
Other	79	189022	8.97	0.91	0.21	1.11	23.39	14.85	4.05	1.90	0.00	0.00
Unknown	4	11032	0.91	2.82	0.34	0.28	89.69	89.69	0.00	0.00	0.00	0.00

* Estimates may be biased due to inclusion of other activities for some sample members.

Table 6.4.11 Percentile Estimates of the Exposed Population CO Levels (ppm), By Type of Environment

	Percentile Point				
Environment	10	25	50	75	90
In Transit	1.03	2.16	3.49	6.20	8.42
walk, jog, bicycle	0.09	0.81	1.80	3.43	4.62
car	1.19	2.46	3.72	6.42	9.81
other	0.51	0.90	2.69	4.79	8.65
Indoors - At Residence	0.07	0.24	0.82	1.62	2.68
sleep *	0.05	0.05	0.44	1.29	1.95
cook - gas stove	0.31	1.25	2.23	3.56	4.93
cook - other/unknown	0.05	0.10	0.61	1.85	4.21
other	0.07	0.33	1.04	2.01	3.54
Indoors-Not At Residence	0.16	0.54	1.11	2.47	4.04
office	0.07	0.53	1.23	2.09	3.69
store	0.05	0.69	1.78	3.29	4.77
restaurant	0.21	0.50	1.40	2.71	4.04
parking garage	0.24	1.81	4.80	13.52	23.28
other	0.05	0.20	0.88	1.75	4.43
Outdoors	0.05	0.10	1.04	2.89	6.19
near road, gas station, construction site	0.05	0.21	1.30	3.10	6.03
parking area	0.33	0.41	1.51	3.37	17.77
other	0.05	0.05	0.07	0.78	2.68

* Estimates may be biased due to inclusion of other activities for some sample members.

	Average CO Level (ppm)
(1) indoors - at residence	1.19
(2) indoors - not at residence	2.04
(3) outdoors	2.62
(4) in transit	4.51

The average CO exposure level for the first of these environments was significantly lower than that of the latter three, and the fourth environment was significantly higher than any of the first three environments. The approximate tests utilized a 5% level of significance.

The results shown in this subsection apply to the "average day" of the data collection period. Additional results -- for high and low CO exposure days -- are shown in Appendix J.

6.4.4 Analysis of Measurement Variability

The Duplicate Measurement File described in Section 5.4.2.3 was utilized for assessing variation in PEM measurements under field conditions. Hourly observations from two or more PEMs were available for 689 hours. It was noted that an extreme deviation occurred between a pair of PEMs at one hour.

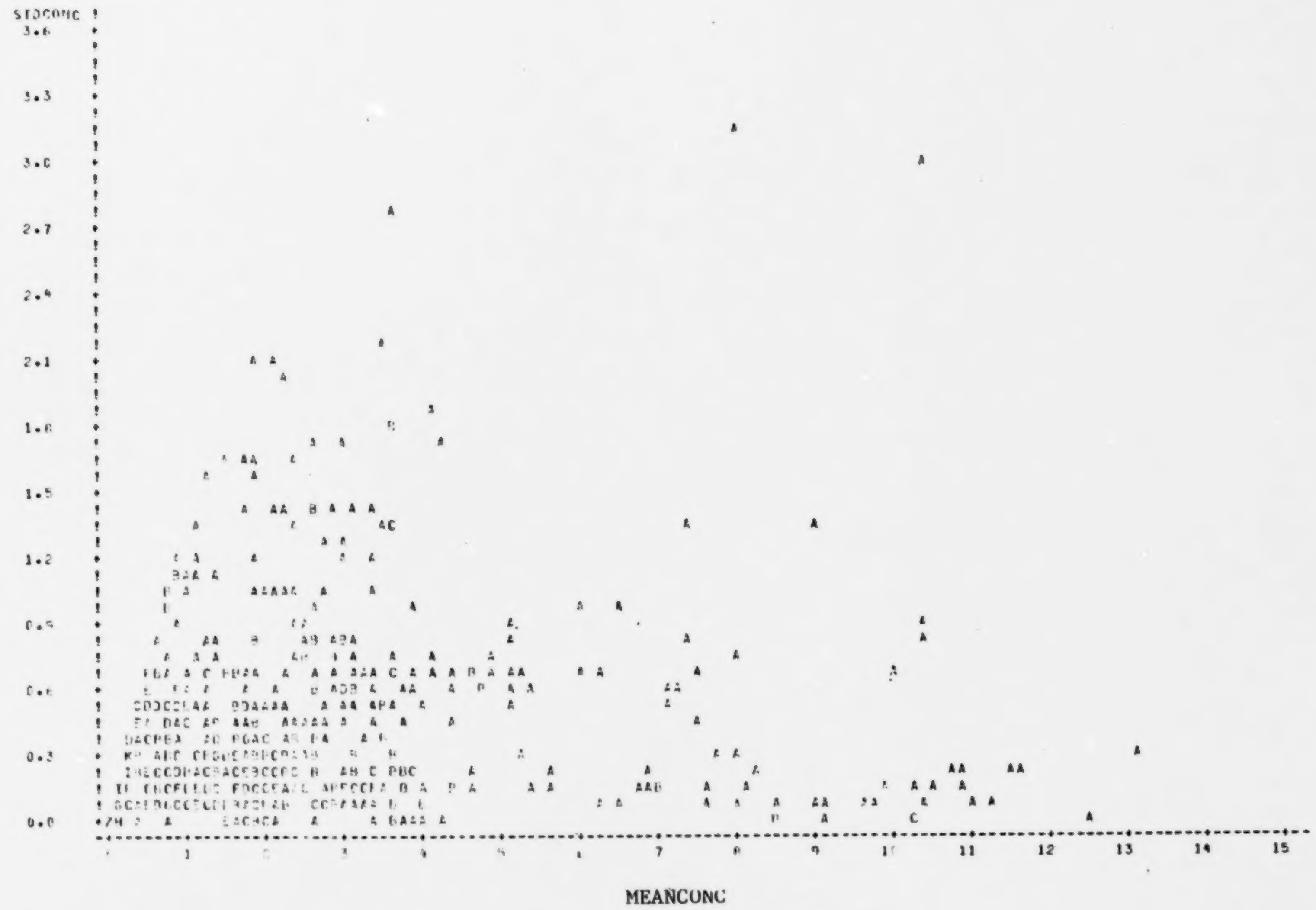
After this outlier was removed, there were 688 hours with two or more CO exposure measurements. Consequently, 688 standard deviations were computed. A plot of the 688 standard deviations (STDCONC) versus their corresponding means (MEANCONC) is given in Figure 6.4.8. Although there is some indication that the standard deviations increase with increasing mean levels, this tendency is not especially strong.

The distribution of the 688 standard deviations is shown in Figure 6.4.9. It should be noted that the vertical axis of this plot is given in terms of interval midpoints. The median of the standard deviations is .25 ppm, and their average is .39 ppm. A corresponding distribution of the 688 coefficients of variation (CVs) had a median of 16.3% and a mean of 30.6 %.

In order to compare the measurement component of variability with person and hourly variations, a variance components model of the following form was estimated:

$$X_{ijk} = \mu + P_i + H_{j(i)} + \varepsilon_{k(ij)}$$

LEGEND: A = 1 observation,B = 2 observations, etc.



NOTE: 36 observations had missing values   15 observations hidden

FIGURE 6.4.8 Plot of STDCONC*MEANCONC

```
MIDPOINT
STDCONC                        Percentage Bar Chart                                                  Cum.            Cum.
     !                                                                                         Freq  Freq       %       %
0.0  !***************************************************
0.1  !********************************************************************************    88    88   12.79   12.79
0.2  !*********************************************************************               137   225   19.91   32.70
0.3  !**************************************************                                  119   344   17.30   50.00
0.4  !**********************                                                                86   430   12.50   62.50
0.5  !*********************************                                                     38   468    5.52   68.02
0.6  !********************                                                                  57   525    8.28   76.31
0.7  !***********************                                                               34   559    4.94   81.25
0.8  !************                                                                          40   599    5.81   87.06
0.9  !***                                                                                   21   620    3.05   90.12
1.0  !********                                                                               5   625    0.73   90.84
1.1  !****                                                                                  14   639    2.03   92.88
1.2  !***                                                                                    7   646    1.02   93.90
1.3  !***                                                                                    5   651    0.73   94.62
1.4  !******                                                                                 6   657    0.87   95.49
1.5  !*                                                                                     11   668    1.60   97.09
1.6  !**                                                                                     1   669    0.15   97.24
1.7  !***                                                                                    3   672    0.44   97.67
1.8  !*                                                                                      6   678    0.87   98.55
1.9  !*                                                                                      2   680    0.29   98.84
2.0  !*                                                                                      1   681    0.15   98.98
2.1  !*                                                                                      1   682    0.15   99.13
2.2  !*                                                                                      2   684    0.29   99.42
2.3  !                                                                                       1   685    0.15   99.56
2.4  !                                                                                       0   685    0.00   99.56
2.5  !                                                                                       0   685    0.00   99.56
2.6  !                                                                                       0   685    0.00   99.56
2.7  !                                                                                       0   685    0.00   99.56
2.8  !*                                                                                      0   685    0.00   99.56
2.9  !                                                                                       1   686    0.15   99.71
3.0  !*                                                                                      0   686    0.00   99.71
3.1  !*                                                                                      1   687    0.15   99.85
     ----+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+-      1   688    0.15  100.00
         1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20
                                       Percentage
```

FIGURE 6.4.9 Distribution of Standard Deviations of Replicate Observations

where X_{ijk} = observed hourly CO concentration for the k^{th} PEM, j^{th} hour, and i^{th} interviewer

μ = overall mean

P_i = effect of i^{th} person (interviewer)

$H_{j(i)}$ = effect of j^{th} hour (within the i^{th} interviewer)

$\epsilon_{k(ij)}$ = effect of the k^{th} PEM for person i at hour k. (The variation associated with this component represents the measurement variation, under field conditions.)

The results of this analysis is shown in Table 6.4.12.

These results indicate that about 5 to 6% of the total variation among the hourly readings is due to deviations in the measurements made by the two (or more) PEMs at the same hour for the same person. The pooled estimate of the measurement variance is .292.

Table 6.4.12 Analysis of Replicate Hourly CO Concentrations

Variance Source	D.F.	Sum of Squares	Mean Squares	Variance Component	Percent
Total	1537	8495.76	5.528	5.615	100.00
Person	27	3562.01	131.926	2.284	40.67
Hour	696	4695.90	6.747	3.039	54.12
Error	814	237.86	0.292	0.292	5.20

Mean	2.35
Standard Deviation	0.54
Coefficient of Variation	0.23

7. REFERENCES

1. Casady, Robert J. and Sirken, Monroe G. [1980]. A Multiplicity Estimator for Multiple Frame Sampling. *Proceedings of the American Statistical Association Section on Survey Research Methods*, 601-605.

2. Chromy, James R. [1979]. Sequential Sample Selection Methods. *Proceedings of the American Statistical Association Section on Survey Research Methods*, 401-406.

3. Cochran, W.G. [1963]. *Sampling Techniques*, *2nd ed.*, John Wiley and Sons, New York, pp. 327-353.

4. Jones, S.M. and J.R. Chromy [1982]. Improve Variance Estimators Using Weighting Class Adjustments for Sample Survey Nonresponse. American Statistical Association 1982 Proceedings of the Section on Survey Research Methods, pp. 105-110.

5. Konijn, H.S. [1973]. *Statistical Theory of Sample Survey Design and Analysis*. American Elsevier Publishing Company, New York, 126-132.

6. McCarthy, Philip J. [1966]. *Replication: An Approach to the Analysis of Data From Complex Surveys* (NCHS Vital and Health Statistics Series 2 Number 14). Public Health Service, Washington, D.C.

7. McCarthy, Philip J. [1969]. *Pseudoreplication: Further Evaluation and Application of the Balanced Half-Sample Technique* (Vital and Health Statistics Series 2 Number 31). Public Health Service, Washington, D.C.

8. Raj, Des [1968]. *Sampling Theory*. McGraw-Hill, New York, pp. 139-163.

9. Shah, B.V. [1981]. SESUDAAN: Standard Errors Program for Computing of Standardized Rates From Sample Survey Data. Research Triangle Institute, Research Triangle Park, N.C.

10. U.S. Department of Commerce, Bureau of the Census. [1978]. The Current Population Survey: Design and Methodology. Technical Paper No. 40. U.S. Government Printing Office, Washington, D.C.

11. Wallace, L.A. and W.R. Ott. "Personal Monitors: A State-of-the-Art Survey," *JAPCA*, Vol. 32, 601.

12. Whitmore, R.W., Jones, S.M., and Rosenzweig, M.S. [1983a]. *Final Sampling Report for the Study of Personal CO Exposure*. Prepared for U.S. Environmental Protection Agency. Research Triangle Institute, Research Triangle Park, N.C.

References (cont'd)

13. Whitmore, R.W., Mason, R.E., Hartwell, T.D., and M.S. Rosenzweig [1983b]. Use of Geographically Classified Telephone Directory Listings in Multi-Mode Surveys. To appear in: Proceedings of the American Statistical Association, Survey Research Methods Section.

14. Williams, Rick L. and Chromy, James R. [1980]. SAS Sample Selection Macros. Proceedings of the Fifth Annual SAS Users Group International Conference.